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ON THE STRESSES OF RIGID ARCHES, CONTINUOUS BEAMS, AND CURVED STRUCTURES.

(*Continued from page* 303.)

OBLIQUE FORCES.

From what has been said as to the effect of transverse stress on the curvature of an arch rib, it will be seen that what determines the change of curvature is the amount of bending moment, and that it is of no consequence whether this has been produced by the action of vertical or oblique forces if the amount be the same. The different conditions already investigated will still subsist under oblique forces, due care being taken to obtain the correct value of M, which can no longer be taken to be represented by the line P N (Fig. F), as in the case of vertical forces.

Curved Dock Gate.—As the condition of dock gates under the pressure of water is in a great degree analogous to that of the voussoir arch, or arch hinged at the centre, the first and most simple illustration of oblique pressures will be that of the curved dock gates of the Victoria Docks, described at vol. xviii., p. 445, of the Minutes of Proceedings of the Institution of Civil Engineers.

Fig. 15 shows a plan of one leaf of this dock gate, the surface exposed to the pressure of the water being circular. The other surface is also circular, but not concentric with the first, the gate being 3 ft. wide at the middle, and only 2 ft. at the ends. The neutral line is shown by the centres of the small circles midway between the two surfaces. The span of the lock is 80 ft.

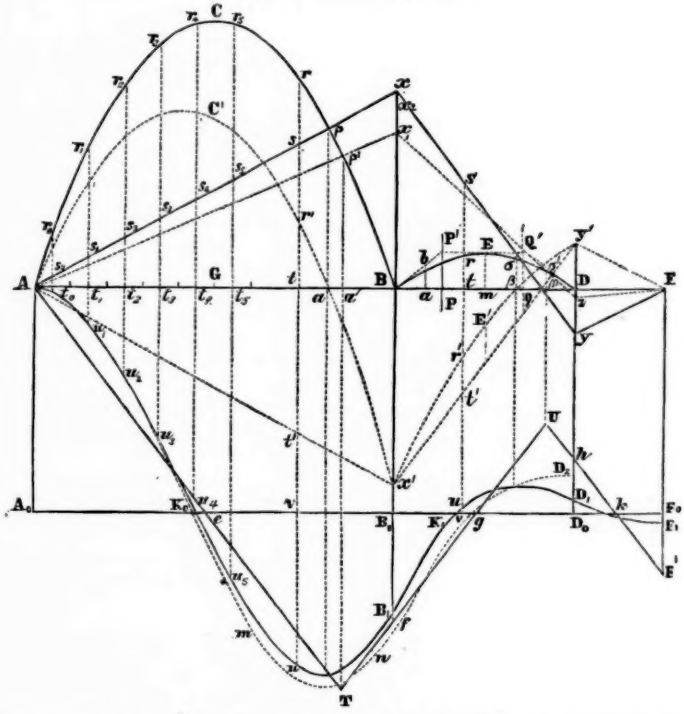
C s_1 s_2 ..... B, being the surface exposed to the pressure of the water, if all the pressures on it be resolved parallel to C D, the resultant may be represented by B D, and will pass through the middle point d of B D. Similarly, if the pressures are resolved parallel to B D, the resultant may be represented by the length C D, and will pass through the point c in the middle of this length. Draw the lines $d\ b$ and $c\ e$ respectively parallel to C D and D B, and therefore in the directions of these resultants. These lines will intersect one another in some point v, and if $a\ b$ be laid off equal to D $d = \frac{1}{2}$ D B, and $b\ f$ be drawn parallel to $c\ e$ and equal to C $c = \frac{1}{2}$ C D, then $a\ f$ to the same scale will be the amount, and will be in the direction of the resultant of all the pressures along C s_1 s_2 . . . . B, and will be normal to this surface.

To construct the curve of equilibrium, which will pass through the heel post A, and some point x in the meeting post, divide the neutral line into a number of equal parts—in the figure there are 20—and draw the normals p_1 s_1, and p_2 s_2, etc., through the middle points of these divisions, cutting the outer surface in s_1, s_2, etc. Then, since the scale used is such that the pressure D B is represented by $a\ b$ or $\frac{1}{2}$ D B, the pressures on s_1 s_2, s_2 s_3, etc, which are all equal, will be represented by $\frac{1}{2}$ (s_1 s_2), and the normals will be the directions of these forces. Draw $x\ h$ parallel to C D, cutting the line $f\ a$ produced in a', and join A a', which will be the direction of the force passing through A. And if $f'\ a$ be made equal

to $f\,a$, and $f'\,g$ be drawn parallel to $x\,h$ to cut a' A in g, $g\,a'$ will be the amount of the force at A, and $f'\,g$ the force at x.

Draw $g\,h$ parallel to $f\,a$, cutting $x\,h$ in h, and $g\,h$ will be equal to $f\,a$ or $f'\,a'$. Draw $h\,q_1$ parallel to $p_1\,s_1$, and equal to $\frac{1}{2}$ of $s_1\,s_2$, and from the point q_1, so found, draw $q_1\,q_2$ parallel to $p_2\,s_2$, and also equal to $\frac{1}{2}$ of $s_1\,s_2$. Continue this construction of the force diagram for the remaining normals p_3, s_3, etc., and if correct, the last point so found will coincide with g.

FIG. H. (CONTINUOUS BEAM.)



The curve of equilibrium is then constructed by drawing from the point r_1, where the first normal $p_1\,s_1$ cuts the line $x\,h$, $r_1\,r_2$ parallel to $a'\,q_1$, to cut $p_2\,s_2$ in r_2. From the point r_2 so found draw $r_2\,r_3$ parallel to $a'\,q_2$ to cut $p_3\,s_3$ in r_3, and continue this construction, which will terminate by the last line drawn passing through the point A, and coinciding with a' A.

In this manner the curves of equilibrium on the figure have been drawn.

The central dotted line shows the curve of equilibrium which passes through the centre of the meeting post, supposing the gates to bear on each other at that point.

It will be observed that, except at the ends of this line, there is a slight amount of transverse stress tending to diminish the curvature of the gate. This stress attains a maximum in the centre of the leaf, where the curve of equilibrium is about 4 in. distant from the neutral line. By the remarks on Eq. (6a), if the gate be considered as a box girder, and the curve touched the outer surface, the compressive stress would there be approximately double of that due to the uniform compression if the curve of equilibrium were central, and at the opposite side the stress would be zero. But as the curve is only about $\frac{2}{3}$ths of the distance to the outer surface, the compressive stress there will be increased to $1\frac{1}{2}$, and at the opposite side will be diminished

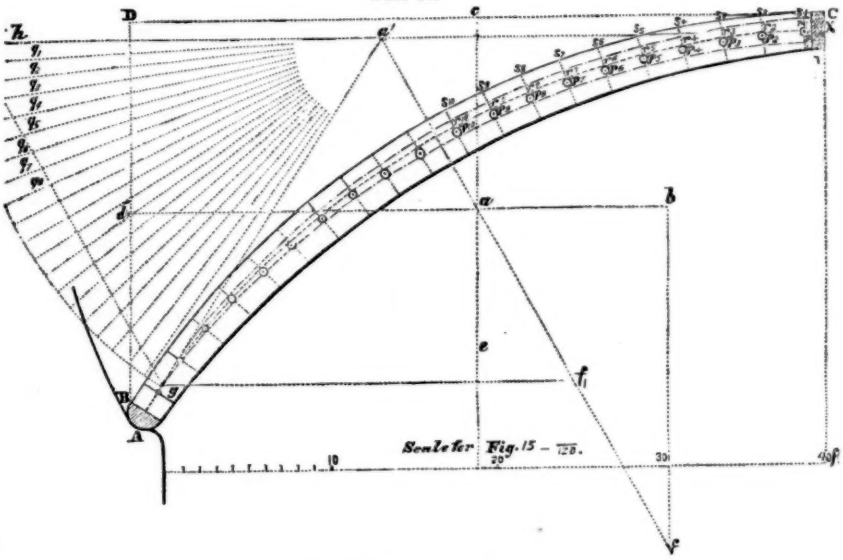
to $\frac{7}{8}$ths of the stress due to the uniform compression.

This result depends on the point of contact of the gates, and these stresses might be altered to $1\frac{1}{8}$th and $\frac{3}{8}$ths respectively by dubbing the timber and making the point of contact about 3 in. nearer the centre of the circle than the middle of the meeting post.

In order that there should be no transverse stress, the curve of equilibrium should be midway between the outer and inner surfaces; this could be easily arranged in constructing gates, by making the thickness so as to satisfy this condition.

The other dotted lines show curves of equilibrium passing through points 3 in.

FIG. 15.



GATE OF VICTORIA DOCKS, LONDON.

distant from the outer and inner surfaces, and are intended to show how the stresses would be altered by an obstruction getting between the gates, and forcing the curve to pass through these points. It will be observed that in that case there would be a gradual increase of transverse stress up to the meeting post.

The curves of equilibrium for a straight gate, or gate of any other form, may evidently be drawn in a similar manner.

Elliptical Caisson.—As an example of transverse stresses on a closed figure, the curve of equilibrium of the elliptical caissons used in the foundations of the Thames Embankment near Westminster Bridge will now be investigated.

These caissons were elliptic cylinders, with a major axis of 12 ft. 6 in. and a minor axis of 7 ft. They were made of wrought-iron plate about $\frac{3}{8}$ths in. thick, and stiffened by angle irons.

Fig. 16 represents a section of the caisson, O being the centre and A O, C O, the semi-axes.

If all the pressures on the quadrant A B C of the ellipse were resolved in a direction parallel to A O, the resultant would be a single force proportional to C O, and passing through the middle of C O. In like manner, the resultant of the pressures resolved parallel to C O would be a force proportional to A O, and passing through the middle of A O.

The intersection of the direction of these forces will therefore be the middle point M of the line A C.

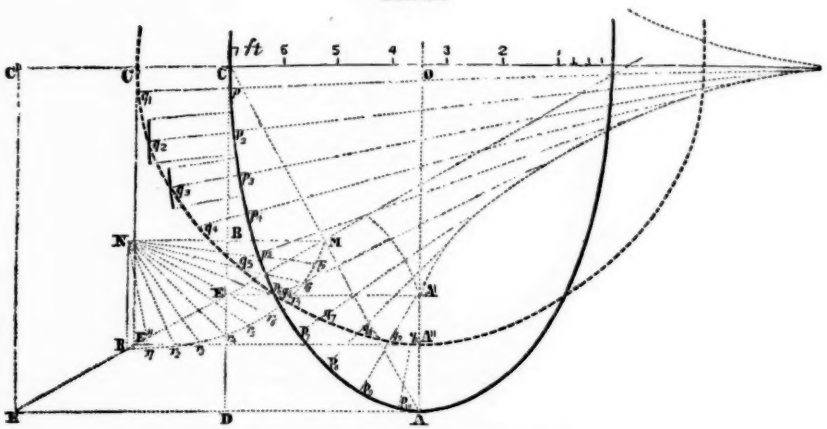
Further, if M N be drawn perpendicular to A O, and the length M N made proportional to the length A O, and N R drawn

perpendicular to C O, and made similarly proportional to the length C O, then M R will be the resultant of all the pressures acting on the quadrant of the ellipse, to the same scale as M N, N R; and the triangles M N R, A O C, will be similar, and have equal angles, and M N being perpendicular to A O, M R will be perpendicular to A C. That is, the resultant M R is at right angles to A C, and passes through its middle point M.

The pressures on the other quadrants of the ellipse may be considered as supplying forces at A and C to hold the quadrant A B C in equilibrium. The force at A will be a force equal to M N, acting perpendicularly to A O, and that at C a force R N, acting perpendicularly to C O. As the directions of these forces do not intersect one another in the line M R, but in a point D outside it, they cannot of themselves balance the force M R.

But the cohesion of the metal supplies the force necessary to produce equilibrium, and the internal stress will be measured by the force so supplied.

FIG. 16.



ELLIPTICAL CAISSON OF THAMES EMBANKMENT, SCALE 1-36.

Equilibrium would be produced by the addition at A of a twisting couple equal to M N×E D, where E is the point of intersection of C D parallel to A O with M R. If E A′ be drawn parallel to C O, cutting A O in A′, the addition of this twisting couple at A would transfer the force M N parallel to itself to A′, and there would be equilibrium, since then the directions of the forces M N, R N, would intersect one another in the line M R.

In like manner, drawing A E′ parallel to C O to cut M R in E′, if a twisting couple equal to R N×D E, which is equal to the above couple M N×E D, were added at C, the force R N acting there would be transferred parallel to itself to C′, and the direction of the forces at A and C′ now intersecting one another in the line M R produced, equilibrium would again subsist. And thus, taking any point A″ between A and A′, and drawing A″ E″ parallel to O C, and E″ C″ parallel to O A, if a couple represented by M N×A A″ were added at A to transfer the force there to A″, and this couple being equal to R N×C′ C″, a couple equal to R N×C C″, would have to be added at C to transfer the force there to C″ and to produce equilibrium, the two added couples being together equal to the couple M N×E D.

Any number of curves of equilibrium therefore can be drawn to pass through points in A A′ and C C′, each curve being subject to the condition that A″ being one point, the other point C″ is determined by drawing A″ E″ parallel to C O to cut M R in E″, and from E″ drawing E″ C″ parallel to A O to cut C C in C″.

Now, since the caisson is symmetrical, each quadrant has the same amount of pressure on it, and therefore the tangents to the curve of the caisson at A and C must be at right angles to one another both be-

fore and after strain ; that is, the condition (3) must be satisfied, or

$$\Sigma (M) = 0$$

between the points A and C.

This is also the only condition, as the caisson is at liberty to change its form, and cannot be considered as of invariable span.

To draw the curve of equilibrium, divide the quadrant C B A into any number of equal parts, 10 in the figure, and at the centre of each part draw the normals $p_1 q_1$, $p_2 q_2$, etc., which will be the directions of the pressures acting on the elementary arcs. From the point R set off R r_1 parallel to the normal at p_1, and equal in length, to the same scale as M N, N R, to the pressure on one of the elementary arcs. From the point r_1, thus found, set off $r_1 r_2$ = R r_1 and parallel to $p_2 q_2$, and continue this construction, which will terminate at the point M.

Then if the points r_1, r_2, etc., be joined with N, N r_1, N r_2, etc., will represent the amounts and be parallel to the directions of the curve of equilibrium at the different points. To draw the curve from C″ draw C″ q_1, parallel to O A, to cut p_1 q_1 in q_1 ; from q_1 draw q_1 q_2, parallel to N r_1, to cut p_2 q_2 in q_2, and continue this construction, which will terminate by the last line drawn passing through the point A″, and having the direction A″ E″.

The point C″ was assumed tentatively, and the values of M found from it. These were the lengths N r_1, N r_2, N r_3, etc., multiplied by the perpendiculars on the directions of these forces at q_1, q_2, q_3, etc., from the points p_1, p_2, p_3, etc.

The position of C″ was then altered until the line was obtained which satisfied the condition

$$\Sigma (M) = 0.$$

In this instance, the pressure per square foot for a depth of 20 feet of water being .56 ton for 1 foot in height of the caisson,

The force M N is	7.14	tons,
and the force N R is	4	"
The bending moment at A is	8.9	foot tons,
" " " at C is	6.6	"

Fig. 16 shows all the details of the construction, as explained above, for one of the quadrants.

The method of construction shows that when the eccentricity of the ellipse is small the curve of equilibrium is very nearly a circle, whose radius is the mean between the major and minor semi-axes of the ellipse. It follows from this that, if the shape of a boiler is not truly cylindrical, there may be considerable transverse, in addition to the tangential, stress ; and if the deviation from the exact circle were greatest at the riveted joints, the stress would be greatest at the weakest parts. It has already been shown that when the curve of equilibrium touches the surface of an arch of rectangular section, the stress on the metal at the surface is quadrupled. The shell of a cylindrical boiler is an arch of this section, in tension instead of in compression, and therefore at an ordinary lap joint, or at any part where the deviation of form from the true circle amounts to only half the thickness of the plating, provided the deviation extends some little distance in the direction of the length of the boiler, the stress at the surface of the metal is four times that due to the pressure of the steam. This important result, showing how greatly a boiler may be weakened by an incorrectness of form too slight, especially if the boiler be made of steel, to be detected by the eye, is not generally known, so far as the Author is aware. There can be little doubt that incorrectness of form, the evidence of which is destroyed when a boiler explodes, is one of the chief causes of many of the boiler explosions which occur, from time to time, throughout the country.

As the circle is the curve of equilibrium for uniform normal pressure, it might at first sight be thought that it would always be the curve of equilibrium ; but an inspection of the figure will show that this cannot be the case. To illustrate the nature of the equilibrium, two of the elementary arcs at p_2, p_3, have been supposed to move parallel to their original positions until the curve of equilibrium passes through their centres. The equilibrium is not disturbed by this movement, but it is obvious that the directions of the forces acting on the ares differ considerably from the normals to the curve of equilibrium.

Rigid Roof acted on by Wind.—In order to show the capacity of the method above explained to deal with complex cases of structure, the next example chosen is the roof of the St. Pancras Station. The form differs from both the circle and the parabola ; the section of the rib varies to some extent near the springing ; and, as the roof will be considered to be strained not only by its own weight, but by the side pressure of the wind, the case is also one of oblique forces.

The particulars from which Figs. 17 and 18 have been prepared were taken from the description of the roof given by Mr. W. H. Barlow, in the "Minutes of Proceedings of the Institution of Civil Engineers," vol. xxx., p. 78.

Each principal or rib consists of a lattice girder of equal top and bottom flanges, and the neutral line is therefore in the middle of the rib, and is represented on the figure by the centres of the small circles. This neutral line has been divided into forty equal parts. At the centre of each of these divisions a vertical line has been drawn to the level of the base line, and a weight has been supposed to act at each of these centres, equal to the weight of the roof for the length of that division, and for 1 ft. longitudinally in the line of the station. That is, since the length of each of these divisions measured along the neutral line is 8.7 ft., the weight has been taken at 8.7 sq. ft. of roof, added to 8.7 ft. run of the weight of the rib. This weight is not the same for each of the divisions; the weight per square foot of the lower portion, which is boarded and slated, having been taken, exclusive of the weight of the rib, at twice the weight of the upper or skylight portion.

For the two divisions at the springing, the weight is that of the rib alone, which is heavier below the part where the lattice girder terminates.

Underneath the lattice girder the value of I for the rib has been taken at double of that for the lattice girder. The base line or termination of the divisions has been placed at that point of the rib, near the bottom, beneath which no appreciable curvature or movement from stress could possibly occur.

The following are the weights which have been assumed.

	Per square foot.	On one division.
Skylight portion	29 lbs.	252 lbs.
Boarded and slated portion	47 lbs.	420 lbs.
Lower part of rib		222 lbs.

From these weights the lines on the lower diagram, Fig. 17, have been drawn. They represent the curves of equilibrium with the weight of the roof only. The line (*a*), corresponding to the rib hinged at the crown, and the line (*b*), corresponding to the rigid rib with the ends kept from spreading, were useful in fixing the position of the line (*c*), which is the curve of the rigid rib with the ends fixed. This latter line shows the actual stresses on the rib. It will be remarked that this line is contained everywhere within the depth of the rib, the neutral line of which it crosses and recrosses several times, the greatest deviation being inconsiderable. The neutral line of the arch rib therefore differs but slightly from the curve of equilibrium, and the transverse stresses arising from the weight of the roof itself are very small.

In Fig. 18, the horizontal force of the wind has been taken at 40 lbs. per sq. ft., and has been treated in the following manner:—From the upper and lower edges of the back of each division horizontal lines have been drawn, the vertical distances between which, in feet multiplied by 40 lbs., give the total horizontal force of the wind acting on the different divisions for 1 ft. longitudinally of the roof. Each horizontal force has then been decomposed into an effective part, normal to the curve of the roof, and a non-effective part tangential to this curve. The effective part, passing normally through the centre of the division, has been decomposed into a horizontal and vertical component. The first has been considered as acting horizontally at the centre of the division, and the second as acting vertically there, and forming an addition to the weight of the division.*

The construction for this decomposition of forces is shown at the bottom of the Fig., to a scale of 100 lbs. to the inch. The total horizontal forces of the wind O 7, O 8, etc., are laid off for the different divisions on the line O X. From the points 7, 8, etc., perpendiculars are let fall on the corresponding normal lines which pass through O, the centre of the arch rib. The lengths of these perpendiculars represent the lost or non-effective forces, and the distances from the feet of the perpendiculars to O, the normal or effective forces. Perpendiculars let fall on the line O X from the ends of the normal forces determine the horizontal and vertical components of these forces.

The directions of the forces acting at each division were then found by laying off to the same scale vertical lines from the ends of the normal forces, each equal to the weight of the division of the roof to

* There is reason to believe that the law of resistance here assumed, viz., that of the squares of the sines, errs in excess of the truth. The construction is therefore a safe one, and the results would probably be approximately true for a considerably greater pressure of wind than that stated in the text.

which it corresponded, as shown by the figures of reference. Lines joining the point O with the upper ends of these verticals give the directions of the forces at each point, and the full black lines which pass through the centre of each division are drawn parallel to these directions.

Having thus found the force acting on each division, and its direction, the resultant of the whole of these forces was then ascertained as follows:

By taking moments with respect to the base line for each of the effective horizontal forces, their resultant or sum is equivalent to a force of 771 lbs. acting horizontally at a point 61.8 ft. above the base line. In like manner, by taking moments with respect to A of the vertical forces, their resultant is equal to a force acting vertically of 14,383 lbs. at a point distant 114.5 ft. from A, or 5.5 ft. from the centre towards A.

Combining these horizontal and vertical forces by construction, it was found that the resultant of the whole acted in the line R R, which cuts the neutral line of the arch rib in a point C nearly midway between the centres of the divisions 19 and 20.

In like manner, the resultant P P of the forces acting between C and A was found, and the resultant Q Q of those acting between C and B.

As the point C is about $\frac{1}{10}$th of the length of a division distant from the point midway between the centres of divisions 19 and 20, $\frac{1}{10}$th of the weight of division 20 was added to the vertical force at division 19, and deducted from that at division 20, in order to make the calculation of these forces correct.

The direction of the thrust at C was then determined by the method of drawing the curve of equilibrium for oblique forces. As a first approximation, the curve was assumed to pass through the centre of the arch rib at the crown. A point in the line R R was found such that when it was joined by straight lines with the points A and B, which straight lines cut the directions of P and Q in the points E and F, the line E F passed through the centre of the rib at the crown, and gave the direction of the thrust there for the rib considered as hinged at the top. The lines E A, F B were then the direction of the thrusts at A and B. The length E p was then cut off on the line E P proportional to the force P. From p the line $p\ k$ was drawn parallel to E F, cutting A E in the point k, and the length E L$=p\ k$ was laid off on the line E F from the point E, thus fixing the point L.*

The force diagram was then constructed by drawing to scale (3,000 lbs. to the inch), from the point L, the line L a equal to the force acting on the division 19, and parallel to its direction; from the end of this line the length $a\ b$ was drawn equal to the force at 18, and parallel to its direction, and so on, the end of the last line coinciding with the point k in the line A E.

Lastly, the curve of equilibrium was constructed by drawing from the point p_1, where the line of force at 19 cuts the line E F, the line $p_1\ p_2$, parallel to E a, cutting the direction of the force at 18 in the point p_2, from p_1 the line $p_2\ p_3$, parallel to E b, cutting the direction of the force at 17 in p_3, and so on, until the construction terminated by the last line drawn coinciding with the line A E, and therefore passing through the point A.

Having thus drawn the curve of equilibrium for the arch hinged at the crown, as shown by the dotted line (a), it was found that this line almost exactly satisfied the condition

$$\Sigma\,(M.y) = 0;$$

the raising of the line at the crown, in order to exactly satisfy this condition, as shown by the upper dotted line (b), being scarcely perceptible. Thus the curve for the rib supposed rigid, and the feet kept from spreading, was obtained.

The curve for the rigid arch with the ends fixed was then constructed after a few preliminary trials, and is shown by the dotted line (c). The springing points of the curve requiring to be raised to A′ and B′, and the vertex to be lowered, to satisfy (3) and (6); the point of intersection of the thrusts at A and B with the line R R was altered slightly, and therefore also the position of the line E F, the points E and F being changed to E′ and F′. To avoid altering the force diagram, the line L E″ was drawn parallel to E′ F′, and k E″ parallel to A′ E, thus fixing the point E″, and the curve of equilibrium was then constructed by drawing the lines parallel to E″ a, E″ b, etc., instead of E a, E b, etc. A similar construction was followed for the other point F.

In drawing these curves, as the directions of the forces at 6, 7, 8, etc., were not verti-

* A somewhat simpler construction is explained at page 394. See Note p. 394.

cal, allowance for this had to be made in the values of M. Vertical lines were therefore drawn on the force diagram through the points *a*, *b*, *c*, etc., to cut the line E L, and any point, as (*m*), was treated as if it formed part of a diagram, where the lines *a b*, *b c*, *c d* were vertical, and the thrust therefore E *m'*, instead of E L; the lengths of the vertical lines *a* β, *a* γ, corresponding to that point and representing M, were multiplied by the ratio $\frac{E\,m'}{E\,L}$, before being put in the summation, and a similar corresponding ratio was used for the other points, where the forces were not vertical.

Referring to the line (*c*), it will be observed that a maximum stress occurs near the middle of the 11th division, at which point the compressive force F is 1.36 tons per sq. in., and the compressive stress on the upper part of the rib caused by the bending moment, is 2.72 tons per sq. in., making together a compressive force on the upper part of the rib of 4.08 tons per sq. in.

The other maximum stress occurs at or near the centre of division 36, and is in like manner 1.88 ton per sq. in. for F, and 2.26 tons per sq. in. for the bending moment, giving together a compressive force at the under part of the arch rib of 4.14 tons per sq. in.

The bending moments or transverse strains to be overcome in producing fixity of the rib at the springing are

At the point A—

(Horizontal thrust = 42.2 tons) × 12.4 feet = 522 foot tons;

and at the point B—

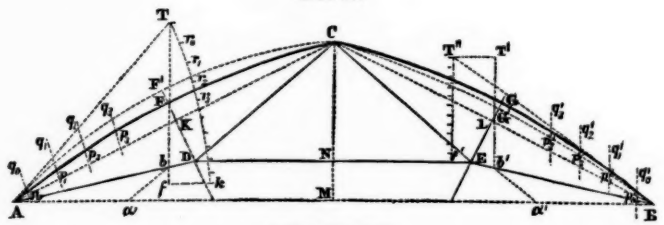
(Horizontal thrust = 52 tons) × 12.4 feet = 643 foot tons.

The difference between these horizontal thrusts is the effective horizontal pressure of the wind on the space between the ribs.

Rigid Arch Braced and acted on by Wind.—When, as in the case of many roofs supported on walls or pillars, the abutments are not constructed to withstand the thrust of the principals, and a horizontal tie-bar becomes necessary, this is generally raised above the level of the points of support, either for the sake of headway or for appearance, and its ends are connected with the apex and points of support by inclined tie-rods. The curve of equilibrium, including the action of these braces, can still be drawn, and will generally differ in form from the curve of continuous curvature already examined.

Taking the simple form of bracing shown by the full lines on Fig. 19, and drawing the lines D F, E G, at right angles to the lines A C, B C, through their middle points K and L, the curves of equilibrium for different positions of the ends D, E, of

FIG. 19.



RIGID ARCH BRACED.

the tie-bar may be compared by assuming these points to be always at the same level, and to move along the lines D F, E G. If the points D and E are situated in the line A B, the curve of equilibrium passing through the points A, C, B, is the same as that found for fixed abutments, by the process already described. As the tie-bar is raised above the level of A B, it appears, by the construction explained a little further on, that the strain on it is increased in the ratio of C M to C N, and the strains on the ties A D, D C, are also increased. The curve of equilibrium changes its form to that of a pointed or Gothic arch A F C G B, the tangents to which, at the apex C, intersect one another in an angle. This useful and economical form of roof is deserving of consideration, and is intended to be used for the roof of the new joint station at Bristol, by Mr. Francis Fox, M. Inst. C. E. The curve becomes flatter and the strains are increased as D approaches K. The principals of a roof, if constructed to these curves, would be without transverse strain if loaded equally on each half of the span;

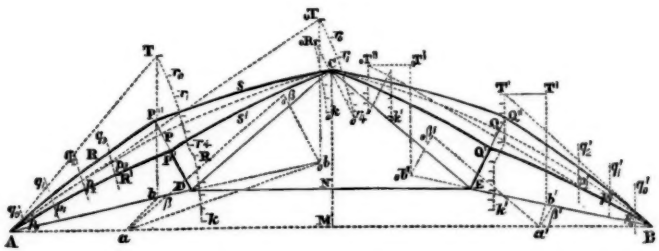
but if an additional weight, or force of wind, be supposed to act on one side A C, and not on the other, the curve of equilibrium would change to some other curve A F′ C G′ B. The point F′ would be further from K than F, and the point G′ nearer to L than G. If the neutral lines of the curves of the principals were originally A F C G B, there would then be an amount of positive or negative transverse strain, measured by the pressure along the curve multiplied by the perpendicular on the tangent, as already explained.

The curve has been assumed to be drawn so as to pass through C, and the transverse strain is, therefore, zero at that point: this amounts to supposing the arch to be hinged at the crown. If it is made rigid there, the curve A F′ C G′ B must satisfy the condition of invariability of span. In order to do this, the curve, drawn by the method described in the former part of this Paper, will pass a little below the point C, and the strain there will tend to increase the curvature.

If the middle points of the principals be directly connected to the points D and E, the rib may have any other shape, as A P″ C Q″ B (Fig. 20), and the transverse stress will be zero at A, P″, C, Q″, B, if the rib be considered as hinged at these points.

The curve of equilibrium corresponding to the position of the points D and E in this figure being A P C Q B, if the points P′, Q″, be farther from D than P and Q, the connections P″ D, Q′ E, will be ties; but if these points are nearer to D and E than P and Q, as at P′, Q, the connections P D, Q′ E, will be struts. In any case, curves of equilibrium A R P″ S C Q′ B, A R′ P′ S′ C Q′ B, can easily be drawn, and are the forms which the neutral lines of ribs ought to have in order to be without transverse strain if loaded equally on each half span. These curves are concave to the straight lines A P″, P″ C, etc., A P′, P′, C, etc., and the amount of their separation from these lines depends on the weight and arrangement of the loading.

FIG. 20.



If an additional load or force of wind be supposed to act on the side A C, and not on the other, the curves of equilibrium have their curvatures increased on the side A C, and diminished on the other side C B. Were the ribs or principals made to the curves of equilibrium A R P″, etc., there would thus be slight transverse stresses, which would be zero at the points A, P″, C, etc., and increase to a maximum at the middle of the distances A P″, P″ C, etc. These stresses would be of opposite signs on opposite sides of the crown C.

If the rib be supposed to be made rigid throughout, it appears to the Author that in the event of unequal loading, the rib will be in the state of a curved continuous beam of four spans; and the transverse stresses, as compared with those on the rib supposed jointed at A, P″, C, etc., will, as for an ordinary continuous beam, be reduced to about one-half; the stresses at P″, C, and Q″ having a contrary sign to those at the middle points of the distances A P′, P′ C, etc.

In addition to the transverse stresses brought on the ribs by unequal forces acting on the two sides of the span, the stresses on the other parts of the frame will be altered. The following construction shows the method of drawing the curve of equilibrium for the braced arch acted on by oblique forces, and of ascertaining the stresses on the other parts.

Referring first to Fig. 19, where the points D and E are unconnected with the principals; having drawn an approximate circular arc for the curve of equilibrium passing through A and C, divide this arc into a convenient number of equal parts, and draw lines $p_0\ q_0$, $p_1\ q_1$, etc., through

the centre of each division in the directions of the forces acting on each of these divisions, as already explained for the roof of the St. Pancras Station.

The upward pressures at A and B may be found by taking moments round B and A of all the forces acting on the structure, including the force of the wind, supposed to act on A C, and the forces at A and B necessary to equilibrate this. If the span of the rib be invariable, or the ends be fixed in position, but not in direction, the forces necessary to balance the effect of the wind on A C, are—

(1) A horizontal force at B acting in the direction B A, and equal to the total effective horizontal force of the wind.

(2) Upward vertical forces at A and B, of such amounts as will equilibrate the effective vertical force of the wind.

(3) A couple whose moment is W.w, if W be put for the effective horizontal force of the wind, and w for the vertical height of its centre of action above A. Calling s the length of the span A B, this couple is equivalent to an upward vertical force W $\frac{w}{s}$ acting at B, and an equal vertical force acting downwards at A, since the horizontal force of the wind cannot alter the sum of the upward forces at A and B. The moment W.w of these forces must be added in taking moments round A and B. If the rib is only fixed in position at one end, as at A, and the other end B is on rollers, the force equal and opposite to W will act at A instead of at B. On this latter supposition, the stresses on the ties are increased.

The stress on the horizontal tie-rod D E is found by taking the moments round C of the forces to the left of C, including the force of the wind. The accuracy of the results may be tested by taking moments to the right of C, including that due to the external forces already mentioned.

In order to draw the diagram of forces; on the horizontal line A B, and with any convenient scale, make A a equal to the horizontal strain on the tie-bar, ascertained as above, and draw the line a b parallel to D C, cutting A D in b; b a will then be the stress on D C, and A b on the tie A D. From the point b draw b T vertical, and equal to the upward pressure at A. A T will be the resultant of the forces A b, b T, acting at A, and will be the direction of the tangent to the curve of equilibrium at the point A. The force diagram is then made by drawing Tr_0 equal to the force at p_0, and parallel to its direction, $r_0 r_1$ equal and parallel to the force at p, and continuing this construction until the last point, k, is arrived at. Drawing k f horizontal and T f vertical, k f is equal to the total horizontal force of the wind, and T f to the sum of the vertical forces acting on the rib between A and C, including the vertical components of the force of the wind.

The curve of equilibrium is constructed by drawing A p_0 in the direction A T to cut p_0 q_0 in the point p_0, from p_0 drawing p_0 p_1 parallel to Ar_0 to cut p_1 q_1, in the point p_1 and continuing this construction for the other points. The last point should be coincident with C, and the tangent to the curve there should be parallel to A k.

For the other side of the span, having made B a'=A a, and drawn a' b' parallel to the tie E C, draw b' T' vertical, and equal to the upward pressure at B, and T' T'' horizontal, and equal to the external force necessary at B to maintain equilibrium. The forces on this side being all vertical, draw T'' f'' vertical, and equal to the sum of the forces acting on the rib from C to B. T'' B will be the direction of the tangent to the curve of equilibrium at B, and f'' B parallel to its direction at C; and by dividing T'' f' into portions representing the forces on each of the divisions of C B, the curve of equilibrium can be drawn between B and C.*

In Fig. 20, where the points D and E are connected to the middle points of the principals, the upward pressures at A and B and the stress on the horizontal tie-bar D E being ascertained as before, the stress on A D is found by taking moments round P'' to the left of P''; the moment of the force along A D balancing the difference between the moment of the upward pressure at A, and the moments of all the forces, including the force of the wind, acting on A P''. Make A b equal to the stress thus found, and A a equal to the horizontal stress on the tie-bar D E. Joining b, a, b a will represent the force to be balanced by the forces of D P'' and D C. If β a be drawn parallel to D C, and β b parallel to D P'', b β will be the stress on D P'', and a β the stress on D C. From b draw b T vertical, and equal to the upward pressure at A, and construct from the point T the diagram

*By supposing the points D and E to be in the line A B, this method of construction may be used for cases like the St. Pancras roof, and is more simple in some respects than the method referred to in the commencement of this Paper.

of forces for the part A P″. From the last point r_5, so obtained, draw r_5 R equal and parallel to $b\ \beta$, and continue the construction from the point R for the part P″ C. The curve of equilibrium is then constructed from the force diagram as before; A T and A r_5 being parallel to the directions of the tangent to the curve A P″, at the points A and P′, and A R, A k, parallel to the directions of the tangents to the curve P″ S C, at the points P″ and C, through which points the curve of equilibrium passes.

For the other side C B, the construction is made in the same manner, care being taken to include the effect of all the forces necessary to maintain equilibrium as already explained.

Figs. 19 and 20 are drawn to scale, and represent a roof of a rise equal to one-fourth of the span, with the ends fixed in position, but not in direction; or without expansion rollers under the end of the ribs. The diagrams of forces on each side of Fig. 19 are also drawn to scale, and show the amounts of the forces acting on one of the ribs, which are supposed to be 20 ft. apart, the weight of the roof to be 10 lbs. per sq. ft., and a gross horizontal force of wind of 40 lbs. per sq. ft., acting on A C. This force has been decomposed into effective horizontal and vertical forces, in the same manner as described for the roof of the St. Pancras Station, and the curves of equilibrium on the diagrams are assumed to pass through the point C, the apex of the roof.

For Fig. 20, forces equivalent to those for Fig. 19 are supposed to act on the roof, and the diagrams of force are drawn both for the curve A P″ C Q″ B, and also for the curve A P″ C Q B; those for the latter curve being indicated by a small $_0$ placed before the reference letters as $_0$ T.

A comparison of these diagrams shows that the stresses are much smaller for the first form than for the second form of roof. The perimeter of the former is, however, a little longer than that of the latter, and although this will slightly increase the surface of the roof, the diminution of the stresses will, on the whole, considerably lessen the cost.

On Fig. 20, the full curved lines are the curves of equilibrium for the roof supposed to be acted on only by symmetrical vertical forces. The curves of equilibrium as altered by the action of the wind, differ so slightly from these as to be nearly undistinguishable on the small scale of the diagram.

EFFECT OF A SMALL ALTERATION OF SPAN.

The span of the arch rib has hitherto been considered as invariable, that being the condition assumed in arriving at Equation (6). But there are several circumstances which induce real or virtual alterations of span; and although these alterations are small, as compared with the length of the span, yet the fact of their occurrence shows that the condition of absolute invariability of span cannot be held to represent the state of an arch rib under strain. The smallness of the alterations, however, allows of the use of the principle of the superposition of small changes; that is, that the total alteration, if small, due to any number of causes, is the algebraical sum of the alterations due to each cause separately.

(1.) By a change of temperature the length of the rib is altered, and its ends, if free, would be displaced, horizontally and vertically, through small, yet measurable spaces, which spaces would be proportional to the amount of change of temperature. If the abutments could be supposed to move through these small spaces, so that their reactions, which existed before the change, could be applied to the ends of the rib with the same intensity and in the same direction as before, the equilibrium would not be disturbed. But as the abutments cannot adapt themselves to these changes, the feet of the arch rib will spread or contract, so as to rest on the same points of the abutments as before, and the span will thus be virtually altered.

(2.) A direct lengthening of the span would be produced if the thrust of the arch forced the abutments farther apart than they were previously to this thrust coming upon them. The amount of yielding of the abutments it is impossible to predict, as it depends on the nature of their foundations as well as upon the bulk and quality of the masonry or brickwork, and there are as yet scarcely any data recorded for existing structures. In a bowstring girder, the lengthening of the tie by stress, or alteration of temperature, corresponds to a yielding of the abutments of an arch.

(3.) The thrust of the arch will compress and shorten the length of the arch rib itself, and will, as appears by the above remark, produce a virtual lengthening of the span. The amount by which the span is lengthened from this cause may be determined by dividing the neutral line of the rib, on a

drawing to a moderately large scale, into a number of equal parts, and laying off on each of these parts a length equal or proportional to the length by which that part of the rib is compressed by the thrust. These lengths depend on the amount of thrust and the sectional area of the rib, and will be equal to one another if this area is everywhere proportional to the thrust. The horizontal projections of the lengths may then be found, and their sum will be the horizontal displacement of the end of the rib, or the virtual change of span.

While arches were constructed of masonry or brickwork, it was only thought necessary to measure the amount of settlement of the crown, which might indicate, though it could not separately measure, a yielding of the abutments as well as a compression of the arch ring. Greater precision was immaterial, for, by the number of its joints and the plasticity of the mortar, an arch accommodates itself to its own internal changes and to a slight yielding of its points of support. With cast-iron arches more minute observations are requisite, while for large arches of riveted wrought iron, where the structure approaches in incompressibility to solid wrought iron, it becomes an important practical question to determine how much the stresses on an arch rib may be altered by an assumed small alteration of the span. The process already described, by which the curve of equilibrium can be found so as to satisfy the condition of invariability of span, gives at once the means of ascertaining this alteration of the stresses.

For, in approximating to that curve, values of M are obtained for one or more curves differing slightly from it in position. For any one of these curves, $\Sigma\left(\frac{M}{I}.bc\right)$, instead of being equal to zero, is a definite quantity; and this quantity may be substituted in Eq. (4), which, as appears by the remarks on that equation, may be written thus:

$$h=\frac{1}{a}\Sigma\left(\frac{M}{I}.bc\right)\Delta s.$$

The value of h, the horizontal displacement, will thus be obtained for a curve whose apex is higher or lower than that of the curve which satisfies the condition of invariability of span by a small quantity, say d.

If, then σ be the assumed horizontal displacement, a curve of equilibrium must be found, which, putting σ for h in the above equation, will satisfy the condition—

$$\sigma=\frac{1}{a}\Sigma\left(\frac{M}{I}.bc\right)\Delta s. \quad . \quad . \quad (13.)$$

Calling δ the height of the apex of this last curve above that of the curve of invariable span, since d and δ are both small, δ may be approximately found by the proportion—

$$h : d : : \sigma : \delta;$$

and the apex of the curve being thus determined, the curve may be drawn and the process verified by ascertaining whether the values of M will satisfy Equation (13).

Having thus obtained the curve corresponding to the displacement σ, the stresses are the values of M belonging to this curve, and may be compared with those of the curve of invariable span.

To give an idea of the change of stress caused by a given small alteration of span, the case of a parabolic, and approximately of a circular, rib of uniform section and small rise, loaded with a weight uniformly distributed horizontally, admits of easy solution.

Let the semi-span=S and rise=D, σ and δ meaning as above. Also let H_0 be the horizontal thrust for the rib with the ends not displaced, and H_1 the horizontal thrust for the curve of equilibrium corresponding to the displacement σ, and rise $D+\delta$. Taking the origin of co-ordinates at one end of the rib, for any abscissa x, let y be the ordinate of the rib or curve of equilibrium for the thrust H_0, and y' the ordinate of the curve of equilibrium for the thrust H_1.

Then

$$y=\frac{D}{S^2}(2Sx-x^2)$$

$$y'=\frac{D+\delta}{S^2}(2Sx-x^2)$$

and

$$M=H.(y'-y)=H_1\frac{\delta}{S^2}(2Sx-x^2).$$

Since the rise is small, Δs may be taken as equal to dx, and it is easily found by integration that

$$\Sigma_0^s M.bc\Delta s=\int_0^s H_1(y'-y)ydx=\frac{8}{15}H_1\delta SD$$

Substituting this value in Eq. (13),

$$\sigma=\frac{8}{15}\frac{H_1\delta SD}{aI} \quad . \quad . \quad . \quad . \quad (14.)$$

In this formula $H_1\delta$ is the bending moment at the crown of the arch, which by Eq. (2) may be put $=\frac{t_0}{k_0}I$, where t_0 is the stress per square inch caused by this bend-

ing moment. Also f may be put for the uniform compression $\frac{H_0}{A}$, per square inch caused by the thrust H_0. Multiplying the numerator of σ in (14) by $\frac{H_0}{A}$ and the denominator by its equivalent f, and substituting $\frac{t_0}{k_0} I$ for $H_1 \delta$,

$$\sigma = \frac{8}{15} \cdot \frac{t_0}{f} \cdot \frac{H_0 S}{A a} \cdot \frac{D}{k_0}.$$

But $\frac{H_0}{A} \frac{S}{a}$ expresses the contraction of a bar of a length S under the force $\frac{H_0}{A}$, or, in other words, the approximate horizontal displacement of the end of the arch rib by the force H_0. Calling this ε,

$$\sigma = \frac{8}{15} \cdot \frac{t_0}{f} \cdot \frac{D}{k_0} \varepsilon,$$

and

$$t_0 = \frac{15}{8} \cdot \frac{k_0}{D} \cdot \frac{\sigma}{\varepsilon} f.$$

For an arch rib of 200 feet span, and 20 feet rise, the depth of the rib being 4 feet, and the cross section I, or box shaped,

$k_0 = 24$ inches,
S $= 1200$ "
D $= 240$ "

And if f be 4 tons per square inch, and $a = 10{,}000$ for wrought iron,

$$\varepsilon = \frac{1200}{10000} \times 4 = \tfrac{1}{2} \text{ inch nearly},$$

$$t_0 = \frac{3}{2} \sigma.$$

If $\sigma = \varepsilon$, or the change of span be equal to the displacement of the end of the rib by the compression,

$t_0 = \frac{3}{4}$ ton per square inch.

Or, the shortening of the span by the compressive force f will be $\frac{1}{2}$ an inch, and the additional stress at the outer surface of the rib at the crown, caused by the virtual lengthening of the span from compression, will be $\frac{3}{4}$ ton per sq. in.

Again making

$$t_0 = f$$
$$\sigma = 2\tfrac{2}{3}.$$

Or a yielding of the abutments of $2\frac{2}{3}$ in. each would double the stress on the outer surface of the arch at the crown, since the total stress there would be $f + t_0$.

The moment of any horizontal thrust being equal to the moment of the weights,

$H_0 D = H_1 (D + \delta) =$ moment of weights.

Substituting the value of δ from this equation in Equation (14), it becomes, writing Aq^2 for I,

$$\sigma = \frac{8}{15} \cdot \frac{D^2}{q^2} \cdot \frac{H_0 - H_1}{H_0} \varepsilon;$$

from which it appears that $(H_0 - H_1)$, or the loss of horizontal thrust, is proportional to σ, the extension of the span.

And if $H_1 = 0$

$$\sigma = \frac{8}{15} \frac{D^2}{q^2} \varepsilon;$$

In the numerical example which has been chosen q may be taken $= 24$, and

$\sigma = 26\frac{2}{3}$ inches

would be the movement of each abutment when the arch had no horizontal thrust, but was in the condition of a girder. It is needless to say that the rib would break long before this extension of span was reached, wrought iron not being sufficiently extensible to admit of the theoretical result being obtained.

The change in length of a bar of wrought iron, by a change of temperature of 15 deg., being the same as for a strain of 1 ton per sq. in., and f being 4 tons per sq. in., if an arch rib of the above dimensions had its temperature reduced 4×15 deg. $= 60$ deg. below the temperature at which its parts were put together, an additional stress would be caused at the outer surface of the rib at the crown, of $\frac{3}{4}$ ton per sq. in. And if the abutments also yielded each $\frac{1}{2}$ in. under the thrust, the stress would be increased from $f = 4$ tons to $4 + 3 \times \frac{3}{4} = 6\frac{1}{4}$ tons per sq. in., by the compression of the arch ring, the reduction of temperature, and the yielding of the abutments. The change of temperature may either increase or diminish the stress, according as it is a fall or a rise; but the compression of the arch ring, and the yielding of the abutments, always conspire together to increase the stress. To overcome this action, a margin should be allowed in the factor of safety, or the span of the arch during construction might be made slightly greater than the distance between the abutments; and before the weight of the roadway was allowed to come on the ribs the span could be shortened by wedging or otherwise.

ELASTIC CURVE AND DEFLECTION OF THE CROWN.

The elastic curve, or the curve which the neutral line will assume under the stresses to which the rib is subjected, may be found in the following manner:—

(1.) Supposing the temperature of the rib to change, the length of each of the divisions of the neutral line will be altered by a small quantity, which will be proportional to the length; and the form of the rib, as

altered by change of temperature, may be considered to be a magnified representation of its original form. Further, by taking, on a drawing of the neutral line of the arch rib the length of a division to represent the alteration of its length, the drawing itself will represent the changes of the different points by the alteration of temperature. That is, if by applying an appropriate scale the alteration of span by change of temperature be measured by the span itself, the rise of the rib to the same scale will measure the alteration of rise, and the horizontal and vertical displacements of any point of the arch rib by change of temperature may be found by applying the scale to the drawing of the neutral line.

(2.) The compression of the arch rib by the force F will cause all its points to be displaced horizontally and vertically through small spaces, which may be determined by the following construction, which assumes that the sectional areas as well as the forces are not uniform throughout the rib:—The amount of the force F at any point can be ascertained by scale from the force diagram used in drawing the curve of equilibrium; and from this, and the sectional area of the rib, the length by which each of the divisions of the neutral line is altered by compression may be found. Taking any assumed point as an origin, a diagram can then be constructed, by drawing through this point a line parallel to the direction of the neutral line at the centre of the first division, and equal in length to the amount by which the length of that division is compressed by the force F, from the point so found drawing a line parallel to the direction of the neutral line at the centre of the 2d division, and equal in length to the amount by which the 2d division is compressed by the force F. This process is to be continued until the last division is arrived at. The horizontal and vertical displacements of a point in the neutral line of the rib, at the centre of any division, will then be the horizontal and vertical projections of a line on this diagram, joining the origin with the middle of the line corresponding to the compression of that division. By this means the horizontal displacement of the end of the rib by the compression may be ascertained.

(3.) The conditions existing at the ends of an arch rib being given, that is, whether the span is invariable, or altered by a small quantity, namely, the amount of yielding of the abutment, and the alterations produced by compression and change of temperature, and whether the ends are free or "fixed," the proper curve of equilibrium to satisfy these conditions can be drawn by the method above described, and the values of M ascertained. The displacements of all the points of the rib by the bending moments M can then be determined by Equations (4) and (5), which may be thus written:

$$h = \frac{1}{a} \Sigma \left(\frac{M}{I} . b c \right) \Delta s$$

$$v = \frac{1}{a} \Sigma \left(\frac{M}{I} . x \right) \Delta s;$$

or in the case of vertical forces (Fig. F).

$$h = \frac{H}{a} \Sigma \left(\frac{P N . P Q}{I} \right) \Delta s \quad . \quad . \quad (15)$$

$$v = \frac{H}{a} \Sigma \left(\frac{P N . A Q}{I} \right) . \Delta s \quad . \quad . \quad (16.)$$

In reference to the limits between which the summations indicated by Σ in these formulæ are to be taken, it is to be remarked that, referring to formula (15), if the summation be performed from A up to B (Fig. F), and the result be substituted in this formula, the value of h is the total horizontal spread of the feet of the arch rib, and this spread must be equal to the sum of the displacements of A and B, from the yielding of the abutments and the alterations produced by compression of the rib and change of temperature. Likewise, if the vertex C were considered as a fixed point the displacement of the point A would be the value of h as obtained by performing the summation between A and C, and substituting this in formula (15); and, in like manner, the displacement of B would be obtained by means of the summation from C to B. But the actual displacements at A and B from the causes enumerated above may, and probably will, in most cases differ from the displacements obtained by considering the vertex C as a fixed point. It will not, however, be difficult to find, by a trial or two, such a point, say C', that the summation from A to C' being substituted in formula (15), the resulting value of h will be the actual displacement of A. This point C' having been found, since the total spread is equal to the sum of the displacements at A and B, the summation from C to B substituted in formula (15) will give for the value of h the actual displacement of B from the above causes.

The elastic curve being then referred to the point C' as an origin, the displacement of any other point as p'' may be found by entering the difference between the summa-

tion from A to C', and from p^n to C', in formula (15). The displacement of p^n may otherwise be found, as in the first method mentioned in p. 71, by performing the double summation indicated by $\Sigma\,\Sigma\,M\,\Delta\,y\,\Delta\,s$, from C to p_n, and substituting this in formula (15), instead of the single summation.

Similar remarks to the above apply to formula (16) for vertical displacements.

Having thus found the displacements of the different points, the elastic curve can be drawn through the new positions of the points so displaced, and the deflection of the crown will be simply the alteration in the rise of the arch rib..

In the case of the parabolic or circular rib of small rise, a formula for v may be arrived at similar to that for σ in Eq. (14).

Putting $d\,x = \Delta\,s$, it is found by integration that

$$\Sigma_0^s (P\,N.A\,Q)\,\Delta\,s = \int_0^s H,\,(y' - y)\,x\,dx = \frac{5}{12} H,\,\delta\,S_2$$

and substituting this value in Eq. (16),

$$v = \frac{5}{12} \cdot \frac{H,\,\delta\,s^2}{a\,I}$$

Combining this with (14),

$$v = \frac{75}{96} \frac{s}{D} \sigma,$$

showing that the deflection is in proportion to the extension of space.

For the arch rib of the roof of St. Pancras Station, not acted on by wind, the virtual lengthening of the span by the compression of the arch rib, found by the construction described above, is .23 in. Substituting this for h in Eq. (15), and taking $a = 8000$ for riveted iron.

I=46 sq. in. $\times 36^2 = 59600$, $\Delta\,s = 8.7$ ft., or 104 ins.

and the horizontal thrust of the rib 46 tons; the resulting value of Σ (P N. P Q), the unit being one foot, is 166. But it appears by Fig. 17, that an alteration of the vertex of the curve of equilibrium (*c*) by one foot, makes an alteration in Σ (P N . P Q) of 900, and for an alteration of 166, the vertex of the curve would require to be shifted 1 ft. $\times \frac{166}{900}$, or 18 ft. This is not more than the thickness of the line on the figure, so that the values of M as altered by the compression of the arch rib may still be taken from the curve (*c*). Making, then, for this curve, the summation Σ (P N . A Q) for the half rib, it is found that the + and — values, 423 and 446, are so nearly equal that the sum may be taken as zero.

The deflection of the crown, therefore, will be unaltered by the transverse stresses brought upon the rib by its own weight.

And thus the deflection will be simply the diminution in the rise of the rib, caused by its own compressibility. This, taking $a = 8000$ for riveted iron, is found, by a diagram constructed as already described, to be .2 in.

As stated in Mr. Barlow's Paper, the observations made upon the rib itself gave from $\frac{3}{16}$th to $\frac{1}{4}$th in. for the deflections, so that the agreement with calculation is very close indeed.

Had the rib not been fixed at the ends, the value of Σ (P N . A Q), estimated from the curve (*b*), would have been — 1648, the unit being one foot; and the deflection, calculated by substituting this value in Eq. (16), would have been 2.4 in., in addition to the diminution of rise caused by the compression of the arch rib.

DIRECT MEASUREMENT OF STRESS.

It would be somewhat difficult, by ordinary methods, to test satisfactorily the stresses on an arch rib, so as to compare them with calculation. Observations on deflection would give some information, but a model would necessarily be on a comparatively small scale, and the rib would require to be curved, yet as much as possible without initial stress.

The Author thinks that when it is desirable to know the stress which any part of a structure or model is sustaining, it is possible to ascertain this by direct observation.

The principle which underlies all investigations of stress, and which has been established by experiment, is that, for working stresses, extension of compression is proportional to stress; or, in other words, the nature of the material, and the extension or compression of a given length of it being known, the amount of stress can be at once determined.

In wrought iron, the extension on a length of 50 in., with a strain of $\frac{1}{5}$th ton per sq. in., would be $\frac{1}{1000}$th of an in. This length is quite within the reach of exact measurement by means of magnifying glasses; since, with a power of 50, it would be equivalent to measuring $\frac{1}{20}$th of an in. by the naked eye. If two microscopes, magnifying even less for iron, and considerably less than this for timber, were attached to a bar of the same material as the structure to be tested, so as to eliminate the effect of alterations of temperature, about 50 in. long, and were each capable of being moved a short distance along the bar by a micrometer screw, it is believed that

stresses of ¼th ton per sq. in. should be read off with certainty. For this purpose, it would only be necessary to furnish the eye-pieces of the microscopes with finely divided scales. By means of the micrometer screw, having set the zeros of the scales nearly to coincidence with two marks made on the iron, at the part where the stress was expected to be the greatest, the readings of the scales before and during the testing would give the stresses in the most direct manner.

The exact value of the scales, in terms of the stress, could be determined, if necessary, by a preliminary experiment on the direct extension of a piece of the material.

It might be said that, owing to the want of homogeneity of the material, the short piece, on which the observation was taken, would differ in extensibility from the part of the structure it was desirable to test. But this objection is not of much force, since experiments on pieces of moderate length, show that the rate of extension for working stresses does not vary, in different specimens of the same material, to nearly the same extent as the breaking weight, which is probably determined by the imperfection of a portion of the material of very limited dimensions.

The measurement of the small extensions or compressions here proposed might even be useful in another way.

It is found that the modulus of elasticity, and the breaking weight, are each greater for wrought than for cast iron, and greater for steel than for wrought iron; and it may therefore be said, though in a very general way, that the less the extensibility, the greater the breaking weight.

This view is borne out by Fig. 21,* which shows some results obtained from experiments when examined under this aspect.

Referring first to the experiments on tensile strain, which are distinguished on the figure by small dots, those for steel and wrought iron have been taken from the "Experiments on Steel made by a Committee of Civil Engineers" (1868—70), and those for cast iron from the Report "On the Application of Iron to Railway Structures" (1849). The fair line A A has been drawn to represent the average of all these experiments.

It will be remarked that wrought iron has about one half the extensibility, and fully three times the strength of cast iron; and that although the strength of steel varied considerably in the different specimens tried, the extensibility was very nearly the same for all—meaning by extensibility, the alteration of the unit of length by a force of one ton per square inch.

The remaining particulars on Fig. 21 have been taken from the experiments on cast-iron bars broken by transverse strain, which are recorded in the second of the above-mentioned Reports, and the fair line B B has been drawn to represent average results.

For each experiment, the extensibility was taken as the reciprocal of the modulus of elasticity, in the ordinary formula which connects the central deflection of a bar with the weight of the load acting on it. The breaking stress per square inch was considered to be that on the outside surface in the middle of the bar, as deduced from the well-known formula, which connects the load, taken as the breaking weight, on the middle of the bar, with the tension on the outer surface in the middle of the span.

It has long been known that the breaking stress, deduced in this manner, was very much higher than any result that could be obtained from experiments on direct tensile strain; and this fact, whatever may be its cause, accounts for the want of coincidence between the lines B B and A A. Mr. W. H. Barlow has examined this subject minutely, and has arrived at the result that in cast iron the breaking stress, deduced from transverse fracture, is about two and a quarter times that obtained from fracture by direct tension.

If the vertical ordinates of the line B B be reduced in this ratio, the line C C is the result; and this line, as will be observed, is nearly coincident with the line A A.

The subject of the connection between the breaking weight and the extensibility is deserving of further examination, as the experiments on wrought iron are few, and have probably been made on good specimens, whereas it would be desirable to examine experiments made on fair commercial samples; and should it be found, that as an inferior kind of wrought iron approaches to cast iron in its physical structure and breaking weight, it also approaches it in the scale of its extensibility for working stresses, an observation of the kind above mentioned, taken where the strain could be accurately determined by calculation, would give the means of ascertaining the quality of the iron used in a structure.

* For Fig. 21 see June No.

ARMOR AND ARMAMENT.*

From "Engineering."

We gave our reasons in a recent article, for negativing the proposal to abandon armor. Even when, if ever, the comparison between the largest guns of the time (used under fighting conditions, not at Shoeburyness) and the thickest armor becomes less favorable to the latter than it now is, we shall expect to find that conclusion still tenable, and still acted upon. Still it is practically certain that in the next few years another great advance will take place in the making of heavy guns, and it behooves naval architects to keep pace, if they do not want the question reopened, and the first principles of their art again thrown into uncertainty. If armor is to hold its present position relatively to guns (we do not admit its uselessness, even if it fails to do this), it is probable that plates of at least 20 in. thickness will have to be afloat before five years are over.

The question is, how is such an enormous addition to weights to be compassed? To thicken the Fury's armor 6 in. all round—which is about what the suggestion amounts to—would involve an addition, we should suppose, of at least a thousand tons of weight. Already her displacement approaches 11,000 tons, and the Admiralty may well hesitate to advance by a mere increase of size, for increased dimensions mean increased cost and diminished handiness, or an impracticable draught of water. On the other hand, there is little or no weight carried by the Fury, like the masts and rigging of her predecessors, of which it is possible to divest her. She cannot do without a hull, or engines, or coals. There is no weight, or very little, to be saved upon these, so that the only hope is in the armor itself. Can any part of this be spared, and the saving applied to thickening the remainder? Before considering the numerous answers which have been given to this question, and trying to ascertain the amount of hope which may be extracted from them, it will be well to analyze the functions which ship armor is supposed to perform.

First, there is a protection of guns and gunners, given, nowadays, in the shape of turrets, and of the armor required to protect their bases. Secondly, protection of steering and conning arrangements, involving an armored tower, more or less large and lofty, but seldom or never reckoning for much amongst the weights of the ship. Thirdly, protected communication between the turrets and conning tower, and the lower part of the ship, including passages for men, air, ammunition, etc.; this is usually obtained by an extension of the armor protecting the bases of the turrets. Fourthly, protection for the ship itself—*i. e.*, for the instrument which keeps all the rest above water, and carries them about.

Of these four services it is often argued that armor, or some equivalent to it, should perform but one, the last. To keep the ship above water is admitted to be necessary, but many authorities entitled to respect are disposed to fight the guns "in the open," carrying the ship's own armor a little higher above water, to make up for *quâ* buoyancy, the loss of the armored battery protecting the guns, or of the breastwork protecting the bases of the turrets. Admirals Elliot and Ryder, the dissentients from the report of the Committee on Designs, proposed, indeed, just the reverse, viz., to protect the guns, and leave the ship unprotected, except by a curious stuffing of cork and air cells about the water line, which no one but themselves imagined would avail to keep the ship afloat. This last device will find no followers, but the plan of concentrating the armor upon the water line of the ship, and leaving the guns to take care of themselves, may obviously force itself upon us, should guns at any time become so powerful that a useful thickness can be reached in no other way. Of this we see no present sign, and therefore protection for the guns appears to us as justifiable and necessary as ever. As to the mode of protection, we see nothing in the least likely to take the place of the turret, which can be applied to a ship launched within five years from now. No form of fixed battery can compete with the turret, and the Moncrieff system has not yet been even tried. That system, no doubt, would save the weight of at least the armor of the turrets—perhaps 400 tons in

* From a late series of articles in our English contemporary bearing the titles of "Substitutes for Armor," Armor Plating," and the "Re-armament of the Fleet," the following is compiled.

a vessel like the Fury; but on the other hand it would give the guns less protection. On the whole, we do not think it worth while to reckon upon this saving, and so include two turrets amongst the weights of the future ship. The conning tower we think it very desirable to retain, if anything whatever is kept beyond a bare belt at the water line.

The third duty, that of protecting the communications between the upper world and the engines, magazines, etc., and preventing the entry of water through the openings in the upper deck of the hull proper, is performed by a mere extension of the walls protecting the bases of the turrets, into a breastwork or battery, which stands upon the middle part of the hull. Whether the breastworks of recent ships can or cannot be shortened, by bringing the turrets closer together, is perhaps a doubtful point; but there can be no doubt whatever of the propriety of keeping these communications guarded, if there is armor both above and below.

The armoring of the hull, *i. e.*, the belt which runs from end to end, a few feet above and below water, and above which rises the breastwork or battery, is the remaining point, and the only one, apparently, where saving can be looked for. Its sole use is to keep water out of the hull, either through shot holes below the water line, which would admit it at once, or above the line, which would admit it in case the ship sunk lower through injuries to the bottom or any other part. Except in so far, therefore, as it forms a downward extension of the protection required for the vertical communications referred to, it might be wholly dispensed with, either by keeping the hull out of the reach of shot (if that were possible in practice as it is in theory), or by constructing the part now protected by armor in such a manner that penetration would not hurt it. Taking the latter plan first, we find several schemes, of which the most noticeable are those brought before the Committee on Designs by Sir William Thomson. He proposed to continue the breastwork (of the smallest possible dimensions) downwards, to meet the hull proper at a depth of about 6 ft. below water. Upon this submerged hull proper, light upper works were to be built, surrounding the breastwork, and these, from the armored deck or shield covering the hull to a height of 4 or 5 ft. above water, were to be filled with cork. Another plan was similar, but the wind-and-water space was to be filled with small hexagonal canisters. Admirals Elliot and Ryder, of course, had their say, and proposed much the same thing, except that all protection for the communications between the hold and the upper world was dispensed with, a kind of cork armor being suggested, which it was hoped might close up after letting shot through, and so remain water-tight. This last plan requires no serious consideration. It was otherwise with Sir William Thomson's, whose proposal to apply cork was inquired into by Mr. Barnaby, who reported (see p. 344 of Appendix to Report of Committee) that "on applying this principle to the Fury, it was discovered that by substituting some 500 or 600 tons of cork for an equal weight of armor, this view could be carried out, but that no increase in the thickness of the armor, or the breastwork, or citadel, was possible."

There is no necessary condemnation of Sir William Thomson's plan in this report, because the belt of cork might be much more effectual in keeping out water than the belt of armor it replaced, only the central part of which, be it remembered, was of the same thickness as that upon the "citadel." Every penetration would admit a certain quantity of water, depending on the size of the hole, or rather cavity, made by the shot or shell, and the quantity of cork, if any, blown out by it. A given number of hits, of average sort, would admit a, no doubt, considerable, but undetermined quantity of water, and it might be argued that of the same number of hits upon armor, one might be expected to penetrate, and, doing so, to admit more water than all the hits together could let into the cork. Although there is nothing absurd about this plan, as there is about the famous "cork cofferdams" of the dissentient members of the committee, we confess to being quite opposed to it, on the ground that exploding shell will play such havoc with cork —throwing it out bodily, burning it, pulverizing it, compressing it—that the compartments intrusted to its care will soon lose their buoyancy, and the ship be sunk or endangered. On the other hand, it is difficult to avoid thinking that Sir William Thomson gave his plan less than a fair chance by carrying cork at the sides as well as the ends of his citadel. That carried along the sides, at the midship part of the ship, would be so much dead weight, or

worse. The only saving from setting the sides of the citadel back from the sides of the ship would be through getting slightly shorter ends or cross bulkheads to it—a gain probably more than balanced by the long strip of heavy armor upon the deck between the base of the citadel and the ship's sides. Had Sir William Thomson made his breastwork shorter and wider, or even wider only, he would probably have found some saving in weight by substituting cork for armor, and so have been able to thicken that which remained. As it was, the cork-protected parts of his ship were less efficient, and the armored parts no stronger, than in the original Fury. A similar result would probably be found if small empty canisters were used instead of cork; in fact it is usually found that any system of small air-tight subdivisions weighs about the same, bulk for bulk, as cork. The principle of carrying out the sides of the breastwork, battery, or whatever the "citadel" may be called, to the full width of the ship, was long since recognized, it may be remarked, by the Admiralty, where, even while the committee was sitting, it was determined so to complete the Fury. That the opposite principle was carried out in the Glatton, and other early ships of the same type, was due simply to the faith then felt in the principle of low freeboard. When that was abandoned there was no longer an object in setting back the breastwork from the sides of the hull proper. In its best form, therefore, the cork-defended ship consists of a central citadel, the full width of the vessel, and no longer than necessary. Outside this the ends, about the water line, form two chambers, reaching 5 or 6 ft. below water, and 4 or 5 ft. above. Our reason for mistrusting the plan has been already given. The cork chambers, under long-continued shell fire, would, we believe, become water chambers, weighing four times as much as in their original form, and therefore a fatal drag upon the ship. Air chambers, whatever the nature of the subdivisions, would, we think, reach this condition still sooner. So far as we can see, therefore, there is no plan for securing buoyancy to a part exposed to fire, which can bear competition with even a moderate protection by armor, and so far, therefore, no prospect is opened of saving the weight of any portion of the hull proper.

The alternative scheme is, as before stated, to keep such parts of the hull as it is desired to relieve of armor altogether out of fire—in fact, to excise or totally remove them. This course is conceivable as regards the ends of the ship—for instance, by letting none of her, except the middle part, rise above water, or even within a few feet of the surface. Some day even this extreme plan may be worthy of debate, but meantime a less startling move in the same direction requires careful consideration. We allude to Mr. Reed's remarkable proposal to build ships with "water tank" ends—to take, that is, the under-water part of the cork compartments of the other system, and to give shot and shell full liberty to do what they like with them, making preparations beforehand for the weight of water which will thus be introduced into the ship. Whatever harm the shot and shell may do, they cannot lessen the buoyancy of structures which lay no claim to *any*, and which are carefully filled with water before the action begins. In fact, the ship "makes believe," in battle, to have no ends at all.

In all the foregoing plans, except one, the inventors cling to the idea of retaining buoyancy at the ends, when damaged, by stuffing them with cork, or other buoyant substances, or by minutely subdividing them—neither suggestion appearing at all hopeful, as we endeavored to show. The one really sound proposal is that made by Mr. Reed, so long ago as 1868, by which the parts not protected by armor are made over to shot and shell, and are expected to bring to the ship's assistance, in battle, no buoyancy whatever. The ends, in fact, are made into water-tanks, from the level of the water-line to a certain distance—say 5 or 6 ft.—below, and the tanks so formed are cut off from the lower parts of the hull by an armored deck. The object of the arrangement, like that of the others, is to lessen the area to be plated, and thus to enable the thickness of the plating upon the part still armored to be increased. Primarily, therefore, it has to be judged by the saving of weight it enables us to effect. If there be no saving—that is to say, if the water let into the "tanks" weighs more than the armor which would be required to protect them—it will not be worth while to adopt the system.

There is, nevertheless, one great advantage, belonging to it, irrespective of weight saved or lost. However thick the armor at the ends of an ordinary ship may be, it

may be pierced, with the result of letting in water more or less extensively, and to the same extent diminishing the buoyancy of the ship. If, on the contrary, there be no armor, but in lieu a chamber already full of water, it is clear that no loss of buoyancy can occur. No amount of destruction which shot or shell can effect can let more water in, so that upon this system the ends of the ship—being absolutely vulnerable—become for all practical purposes absolutely impregnable. You are certain that they at least will never endanger the ship by letting in water—whereas, under the present system, they are special sources of danger, inasmuch as, from a natural desire to get a maximum thicknesss over the central and most vital portions, no ship is ever given the same thickness of armor all round the water line; hence, that carried at the ends is rarely more than from half to two-thirds the thickness of the plating abreast the engines and boilers. Of late years even the best armor a ship carries has been but a doubtful match for the guns she may reasonably expect to meet (say such as she carries herself); consequently the chance of penetration at the ends—where the armor is so much weaker—is very great in all our iron-clads. At the ends there is, no doubt, a more perfect system of subdivision into water-tight compartments than is possible amidships; but the end armor of all iron-clads is so weak relatively to the guns likely to be brought against it, that several compartments may well be penetrated at once by a shot which has passed through the armor at a considerable angle. There can, in short, be no doubt that the present system of armoring saddles ships with weak places, which the water tank system of Mr. Reed abolishes altogether. Hence it has strong claims to regard, irrespective of any saving in weight it may promise to effect. The other "central citadel" plans—those which contemplate cork or air-cells at the ends—merely substitute one kind of weak place for another.

But the practicability of the scheme turns, as already stated, upon considerations of weight, and unfortunately a little reflection suffices to show that Mr. Reed's plan, in the form in which he sent it forth, promises little help in the immediate present. Roughly speaking, each of the proposed end tanks forms an isosceles triangle, of which the base is the end, or cross bulkhead, of the central citadel or battery. If armor be removed from the two similar sides (*i. e.*, from the sides of the ship between the extremity and the points where the battery commences), it needs to be put on upon the base instead. In other words, the cross bulkhead of the battery needs to be completed downwards to a considerable distance under water, in fact until level with the bottom of the tank, instead of stopping, as now, at the level of the upper edge of the belt armor, some 3 or 4 ft. above water. If this were not done, a shot entering the tank in a raking direction might pass without obstruction into the body of the ship. To complete the bulkhead to this depth makes a considerable hole, it need hardly be said, in the weight of the armor saved from the sides, and when the balance is ascertained it will be found that it is far exceeded by the weight of water let into the tank—unless the thickness of the armor dealt with is very great indeed in comparison with the width of the tank. In many cases a water tank may pay better than armor at the very extremity of the ship, where the sides are very close together, but as soon as the latter begin to separate so as to give room for a considerable weight of water between them for each foot of the tank's length, the system is found to fail utterly—that is, when applied in connection with any thickness of armor which it has yet been proposed to carry upon the ends—or for that matter upon the middle—of a ship of war. In other words, there is a large increase of weight, which might just as well be applied directly to thickening the armor, if any increase of displacement is to be allowed.

Mr. Reed explained his views before the Committee on Designs for Ships of War, in these words: "Have at the end a deck situated at a certain depth. The space above that deck I propose to fill with water, which cuts off the whole of the lower part of the ship from injury from shot, and relieves you from the necessity of armoring more than a portion of the length. The Committee evidently jumped at the proposal, and appear to have asked the Constructive Department of the Admiralty for more information, for at page 344 of the Appendix is a report by Mr. Barnaby, in which the following passages occur:

"The calculations made in 1868 show that it might be possible, on the plan conceived by Mr. Reed, to build an unmasted

ship of 6,580 tons, having about 21 in. armor, 1,000 tons of coal, and a speed of 14 knots, on the assumption that the armored citadel is only 6 ft. above the water line, and that the guns are unprotected. The weights would stand as follows:

	Tons.
Weight of hull	4,200
" armor	2,665
" machinery	1,250
" coals	1,000
" water and armored deck at extremities	500
" guns and stores	1,000
Displacement =	10,615

"Mr. Reed's investigation showed:

"1. That to secure the advantages of this system it is necessary to apply it to ships of large tonnage, say 6,000 tons and upwards.

"2. That but little advantage is gained in ships of the ordinary proportion of breadth to length, and that ships must be built much shorter and wider in order to apply the system successfully.

"It would be necessary, for example, in the ship referred to above, of 6,580 tons, to adopt the proportion of 4½ beams in the length, and to make the ends very fine. If the proportion of 6 beams in the length be taken, and the usual fine lines, then, with the same tonnage and speed, the armor on the central citadel would be only 11½ in. instead of 21 in., the weight of armor being 1,300 tons, and that of water and armored deck beneath it being 800 tons."

The remark as to tonnage may be at once disposed of, being based upon the mischievous old rule which the Admiralty last year abandoned. Displacement is now, as it ought to be, the standard of measurement, and the proposed ship actually displaces about 200 tons less than the Fury, so that she need not be objected to on the ground of size. If her coal supply be assumed to be increased to an equality with the Fury's, the two ships may be considered about equal in displacement, and as they are equal in speed, a fair comparison may be drawn between them. In the first place, owing to the less favorable form, greater power will have to be indicated to gain the same speed; hence the coal supply, though supposed equal, will not last for as many days' steaming as the Fury's. In the next place, the total weight of armor carried does not differ materially, we believe, from that carried by the Fury, and though it is difficult to deal with a design of which so few particulars are given, we believe that if the central citadel be raised to the same height as the Fury's breastwork, and turrets and conning tower added, the thickness of armor must be reduced from 21 in. to 14, *i. e.*, that now carried by the Fury. In other words, the Fury has been shortened and widened, with no particular benefit beyond getting rid of certain weak points in her water line. There is evidently little to hope from the water tank system when applied to ships armored like the Fury.

Keeping to the thickness of armor mentioned by Mr. Barnaby—21 in.—there is, however, a good case for the tanks. It is decidedly better to make the ends into tanks than to place 21-in. armor round them, though even in the case of a ship carrying that great thickness of armor, it would, according to the usual scale, be not 21 in., but 12 in. or 14 in. plating which would be applied to the ends—a thickness which it would save nothing to replace by a tank. Still the fact remains that Mr. Reed showed us, five years ago, how this enormous thickness of armor could be carried upon a vessel no larger than the Fury, though limited to the water line.

Obviously the only way to get such armor as this applied to the protection of guns as well as water line, is by shortening the "central citadel," and using up in turrets, etc., the armor saved. But this can only be done by extending the area of the tanks—which is just what Mr. Reed evidently is anxious not to do. He goes out of his way to give very fine ends to a short and beamy ship, which would probably be faster, and would certainly carry more weight, if allowed water lines of more usual form, his object being clearly to keep the tanks as small as possible, because, when brought to the broad part of the ship, they weigh more than the armor they replace, even though the latter be 21 in. thick. Hence on Mr. Reed's system any further shortening of the central citadel implies a further shortening of the ship, and a further diminution in the ratio of length to breadth. He gives us, in fact, an oblong fort, with just a little wedge (a water tank) stuck on at each end as a cutwater, and all depends upon keeping the wedges small in proportion to the oblong. If we want to shorten the fort without reducing the displacement, we are not at liberty to increase the area of the wedges, but must, *nolens volens*, increase the beam.

What prevents the application of tank ends to ships like the Fury, and must even prevent their application, to anything like the extent which could be desired, to vessels with a much greater thickness of armor, is simply the enormous weight of the water admitted to the tanks, when the latter approach the broader parts of the ship. The objection is complete and fatal, and until it can be removed, Mr. Reed's ingenious plan must continue to disappoint the sanguine expectations which one is apt at first sight to base upon it.

Happily there is a way, and a very simple way, out of the difficulty—so simple, indeed, that its not being referred to by Mr. Reed is a matter for some surprise. All that has to be done, in order to make Mr. Reed's water-tank system applicable to ships like the Fury, and applicable to as large a portion of the ship as may on other grounds be desirable, is to stow in the tanks as much of the vessel's coal supply as they are able to contain. This done, the utmost amount of water they will be liable to admit will be that which can be contained in the spaces between the lumps of coal, or but little more than one third the water which the tanks would hold if treated as water tanks only. The tanks are made, in fact, into coal bunkers, for which they are sufficiently well adapted. When emptied of coal, wholly or partly, there is of course room for more water, but the extra quantity admitted serves merely to make good the weight of the coal consumed, and to keep the ship at her proper draught. Thus modified, Mr. Reed's tanks can be applied not only at the ends, but even at the broadest part of the ship, with an actual saving of weight.

The credit of this modification belongs, we believe, to Mr. Michael Scott, who first started the idea in a paper read before the British Association in 1870, and published as a pamphlet in 1871. This paper is, however, little more than an explanation of Mr. Reed's plan—Mr. Scott appearing not to be aware that Mr. Reed had anticipated him—with some scant references to the use of the tanks as bunkers for fuel. There is nothing in the paper to show that the author realized the immense importance of the distinction between tanks which carry fuel and those which carry none, and the comparison instituted between a ship thus built and an ordinary breastwork monitor (of that date) is too cloudy, for want of any clear statement of dimensions, weights, etc., to do proper credit to the author's ingenious suggestion. The only figures stated with any distinctness are those referring to the presumed saving of armor, which is put at 1,000 tons, in a ship with 12-in. plating—a preposterous claim, fully three times too large. No allusion is made to means for making the use of the tanks as coal bunkers practicable (not an easy thing to arrange), and they are shown in the drawing which accompanies the pamphlet as subdivided to a degree inconsistent with such a mode of utilizing them. Moreover, the *entire* exclusion of water from the tanks (when loaded with fuel) appears to have been aimed at by carrying patent fuel, formed in close fitting blocks, in lieu of coal, an idea which, however ingenious, was open to the objection of bringing two novelties into the scheme instead of one. Altogether, it is not wonderful that Mr. Scott's suggestion, valuable as it is, has received little notice up to the present time, though whether the Admiralty has taken any steps respecting it since 1870 we are not able to say. It is not, however, likely that Mr. Barnaby has overlooked the importance of so valuable an idea. It certainly has not been applied to any ship, but no ship upon which it could be tried has been laid down since that year, and the Fury was in too advanced a state to be interfered with when Mr. Scott published his plans. It may be, therefore, that the Admiralty has been designedly keeping the matter quiet, and forbearing to excite the interest of foreign powers until the time for designing a new ship should arrive. A new Fury, it is understood, is now in preparation, and we venture to say that no more important question can be considered, in connection with the new design, than that to which we have directed attention.

THE RE-ARMAMENT OF THE FLEET.

The successive growths of our iron-clad fleet from 4½-in. iron clothing to 6-in. armor, and thence to 8-in. and 12-in. plating, has brought with it a corresponding gradation of ordnance. As a necessary consequence of this gradual increase of armor and weight of guns, the armament of the fleet has got into a very confused state. As the 6½-ton gun era corresponds with the 4½-in. and 6-in. armor period, ships with those thicknesses of plating remain armed with that comparatively small weapon. Whilst the 8-in. and 16-in. armor synchronizes with

the period of the 12½-ton and 18-ton ordnance, ships so protected are armed with weapons of these weights. Now that 12-in. plating protects more recent vessels, 25-ton and 35-ton guns come into being.

Were it possible to do so, it would evidently be most desirable to re-armor the whole fleet, so as to bring the defensive value of the elder ships up to that of the later vessels. That, however, is, we need hardly say, impossible. The structural improvements which enable the architect to concentrate a greater weight of armor upon a smaller portion of the hull could not be introduced into existing ships. No such difficulty, however, obtains as to concentrating the weight of ordnance into fewer guns. Beyond certain alterations of the ports, and strengthening of the decks, no insurmountable obstacle exists to replacing the 6½-ton gun by the 35-ton gun, provided the gross weight of armanent be not greatly increased. As to working the 35-ton gun on the broadside, all the mechanical difficulties have been successfully overcome by Captain Scott. His carriage for the 25-ton broadside gun enables that weapon to be readily worked at sea by four men; and, doubtless, by his mechanical appliances, 35-ton guns will be worked more easily and safely by fewer men than the existing 6½ ton guns, which have not yet been furnished with his mechanism.

There are, then, no great difficulties in the way of that re-armament of the fleet which thoughtful naval men so urgently desire, and which "Fraser's Magazine" so strongly advocates.

The Royal Alfred, though an old wooden iron-clad, carries 1 ton of ordnance to every 36 tons of ship. Taking that proportion as the standard of comparison, it will be seen tnat all the ships subsequently built carry less armament and more armor. But it is not so much to the weight of ordnance carried as to its faulty distribution that we wish now to refer. Take, for example, the following ships:

	Tons of Ordnance carried.	Pieces.
Minotaur	193	26
Agincourt	218	28
Northumberland	261	28
Black Prince	192	28
Warrior	195	20
Bellerophon	145	13
Royal Alfred	177	18
Royal Oak	166	24
Zealous	130	20
Vanguard	139	14
Hercules	195	14
Sultan	194	12
Monarch	131	7
Devastation	140	4
Glatton	50	2
Hotspur	32	3

In the day of battle it will be utterly impossible for seamen to single out foes armored with precisely similar plates to those of their own ship. Nor, if a choice of foes were possible, would a thick plated Devastation single out a similar vessel for a couple of hours' battering, when, by a brief effort, she might sink a Zealous, and discourage the hostile fleet. But if the guns of the Zealous were as capable of perforating the Devastation as that ship's guns are of riddling the Zealous, then the latter vessel might make a good fight for life; and who, considering the chances of battle, would venture to say that the odds would be overwhelming if she carried the British flag. What, however, "Fraser's Magazine" contends for, is not that thinly-plated ships would ever be equal to the more thickly-armored vessels, but that the former vessels should be given a fair chance in battle by carrying weapons which would perforate the thickest armor afloat.

It will be many years before the earlier built iron-clads cease to exist; and should a maritime war intervene these vessels must fight whatever hostile ships they may fall in with. It is not the custom of the sea for opposing ships to exchange information as to thickness of their armor before commencing an action; and if otherwise known to be greatest on the enemy's side, why must the Northumberland, a British iron-clad of 10,584 tons weight, be compelled to run away? The British ship has now no other expedient, because her guns are of an obsolete weight. Let her 28 pieces, weighing together 261 tons, be changed for 8 pieces of 280 tons, and then the Northumberland may be fairly expected to try the fortune of war with a hostile Devastation.

Though there is no way of furnishing guns with adequate destructive power, without increase of weight, yet it is unfortunate that British ordnance should have, in the words of the late Ordnance Select Committee, "decidedly the lowest velocities." For, as striking force varies as the squares of the velocities, it obviously follows that British rifled guns have necessarily "decidedly the lowest" perforations. This loss of velocity, and consequently of strik-

ing force, increases with the weight of the projectile to be rotated, as might naturally be expected when it is remembered that the rifle bearing which both supports and rotates the shot, is the same whether the shot be 115 lbs. weight, or 700 lbs. in weight. The 35-ton gun is necessarily the greatest loser from this cause. The increased loss of perforation in the case of the 35-ton gun, may be understood by comparing its performances with those of lighter guns similarly rifled. Thus, a 6½-ton gun yields a "penetrating figure" of 85 foot-tons per inch of its 7-in. 115-lbs. shot's circumference. By doubling the weight of the gun and shot, the "penetrating figure" becomes about one half more, *i.e.*, a 250-lbs. shot issues from a 9-in. 12½-ton gun with a striking force of 125 foot-tons per inch of its circumference. Doubling the weights of both once more, the "penetrating figure" increases as before to about one-half more, *i.e.*, a 12-in. 600-lbs. shot issues from a 25-ton gun with a "penetrating figure" of 188 foot-tons per inch of its circumference.

Again, a 9-ton gun yields a "penetrating figure" of 100 foot-tons per inch of its 8-in. 180-lbs. shot's circumference. By doubling these weights the "penetrating figure" is increased two-thirds, *i.e.*, a 400-lbs. shot issues from its 10-in. 18-ton gun with a striking force of 166 foot-tons per inch of its circumference. But when these weights are doubled once more, only one-third higher "penetrating figure" is attained, *i.e.*, a 700-lbs. shot leaves a 12-in. 35-ton gun with a striking force of 220 foot-tons per inch of its circumference, instead of 276 foot-tons if it rose two-thirds, or 249 foot-tons if it rose one-half. That is to say, if the 35-ton gun followed the law of increased perforating power which obtains by doubling the weights from the 9-ton gun upwards, it would perforate 21 in. of armor with service backing; and if it followed the law which obtains by doubling the weights from the 6½-ton gun upwards, it would perforate 19 in. of backed armor, instead of 16 in. as at present.

Even supposing that having "decidedly the lowest velocities" only involves the loss of 2 in. additional armor perforation in the 700 lbs. shot, this would not be a light loss in the day of battle. But the armament of the Northumberland and her consorts needs not only an accession of velocity, but an accession of weight in the projectile, and hence the necessity for the employment of heavier ordnance.

The only grave objection to this re-armament of the British fleet is stated by "Fraser" to be the great loss of endurance which the present rifle system gives rise to in the heavier guns. Naval men are alarmed at the idea of resting the safety of the fleet and the security of the country solely upon an armament of 35-ton guns. They observe that the only gun of that nature tested so far, gave way after 38 horizontal discharges with mild pebble powder, spread over three and a half months; and that those furnished to the navy have only been proved by firing, at long intervals, three reduced charges horizontally. Practical gunners are of opinion that, if such guns were, after a few years' ordinary training practice, taken into a naval bombardment to fire 20 elevated rounds per hour, they might fairly be expected to break down during the first hour. That is to say, that the strains to which the "Woolwich Infants" would be subjected during a naval bombardment would be about twice those under which the late "Infant" succumbed when carefully "nursed" at Woolwich. This is the only serious objection to the re-armament of the fleet. It is one strongly felt by the navy, and the opinion of the navy on a point of that kind cannot be lightly disregarded. Indeed, it is generally understood that this lack of endurance in the heavier guns is the only cause that the armaments of the fleet are suffered to continue in their present obsolete condition. Without some such good reason, the Ordnance Department of the Navy would be deserving of severe reprobation for allowing the fleet to fall into its present low artillery condition.

Works are being erected in Pittsburg to manufacture pressed bricks with enamelled facings. The enamel is made of various colors to suit the tastes of architects or builders, and as it is impervious to water or acids, having a surface that can be cleaned like glass, it is well adapted for building purposes in the smoky cities of the West. The enamel is claimed to increase the strength and durability of the bricks, while giving all the beauty of surface to be obtained from stone or marble. The cost is said to be $20 per thousand over common pressed brick.

ON RENDERING WOOD INCOMBUSTIBLE.

By D. O. MACOMBER, C.E.

From the "Journal of the Society of Arts."

Man is surrounded by what in former times have been called the four elements, viz., earth, air, water, and fire; but modern science has demonstrated that earth is composed of many earths; air, a compound of at least two gases; water, a compound of hydrogen and oxygen; and fire, only the production of light and heat during combustion. For our present purpose, however, it is most convenient to consider them as original elements, and as such they are all intimately connected with our subject of this evening, viz., rendering wood incombustible.

To the earth man is indebted for food, clothing, and the mineral and metallic substances which, together with the rocks and carbons, form the bases of all the improvements and progress of the world.

Air, which forms the vital principle of life, and upon the purity and abundance of which depends our health, and the total loss of which is death, is not less important, inasmuch as modern science is rapidly converting it, by condensation, into a controllable motive power.

Water, which forms the far larger portion of the surface of the globe we inhabit, as well as of our own bodies, and of all animal and vegetable life, seems to have been the parent of all the other elements, for it dates its existence in chaos, and claims priority by the creating hand of the great God of the universe. Of all the elements it seems the most wonderful in its functions and transformations. It descends in genial showers to water the thirsty earth, or it deluges a world and sweeps man and beast away in its course. It is invisibly absorbed in the atmosphere, and it is poured down in the destroying water-spout. It floats the navies of the world, and it swarms with curious animal and vegetable life. You may burn it, or extinguish a burning with it. It softens, permeates, and cooks our food, quenches our thirst, and supplies the greatest modern power of the civilized world. You may burn, evaporate and scatter it abroad, but you cannot really waste a drop of it. You only change its condition. It is in the vapor, the atmosphere, and the world yet.

But fire is the friend, the slave, the master and the consumer and conqueror of man and his works. Although the true definition of fire may be merely "solid or gaseous matter at a high temperature," yet by fire we understand the activity of heat, when supported by an amount of atmospheric air sufficient to consume or disintegrate those bodies to which it is supplied, or with which it comes in contact. If we look above by day (when fog and clouds permit) we see the great source of light and heat, 95 millions of miles distant, and modern research proves it to be a monstrous globe of active fire, flashing its flames out hundreds of miles from its body. If we search below the surface of our earth, we find the temperature rising (as we sink our shafts) one degree for every 60 ft., until at 2,500 feet deep (could we reach it) lead would melt, at 74 miles cast-iron, and at 190 miles rocks would be fused, and every known substance become liquid; the thin crust of the earth is passed, and heat reigns supreme.

But with all this a kind Providence has placed within the reach of man, guided by reason and science, the means of in a great measure controlling this destructive element, and rendering it obedient to our wills, a powerful auxiliary of progress in all the arts that minister to man's happiness, his warmth, comfort, and satisfaction. But it is not to be overlooked that the higher we advance in civilization, the more boldly we stretch out into the fields of invention, progress, and improvement, the more intimate we become with the daily use and contact of this element.

Man in an uncivilized state requires heat for two purposes alone—warmth and cooking his food. In the countries under the tropics, where the sun furnishes heat in abundance, and ripens the abundant fruits of the earth, artificial fire is but little needed. In high northern latitudes, likewise, it is not a little singular that only a small portion of the fat of those animals which are used for food and for clothing, furnishes all that seems to be required for light and warmth; and the inhabitants of those apparently inhospitable regions enjoy all the comforts of home and kindred, with an increased attachment for their birthplace and climate, compared with the

natives of more genial skies and brighter lands.

In the construction of the habitations of man, when the world was young, the materials nearest at hand were the trees, bushes, leaves, and grasses, which the temperate zone produced. These, as they became dry by exposure to the sun and air, became highly inflammable, and we may well suppose were often destroyed, even with the scanty use of fire of that period. But as man increased in numbers and began to build cities, he sought for more solid and durable materials. Stone, where it could be found in abundance, and unburned brick of clay or mould, as the best substitute for stone, was used, until wealth, taste, and love of the beautiful began to be developed in the use of marble and precious stones, as the interior of tombs, palaces, and pyramids testify. But ever and always the use of wood was predominant, as is proved by the fact that cities have been destroyed by fire from the earliest ages of antiquity. Indeed, it is scarcely possible to know how all the interior doors, casings, carvings, and adornments of every kind could possibly have been wrought in any other material than wood. And so it has been in every age, and so it has come down to the nineteenth century. We do not mean to say that iron, stone, brick, or plaster may not be used throughout a church, a palace, a house, or a store, but the cold and rigid nature of either of these materials, to say nothing of the enormous cost, will probably always exclude them from universal use in interior ornamentation, and most certainly in furniture.

In the use of wood for any and all constructions for human habitations there are mainly but two objections, its liability to be destroyed by time and by fire. And it is not a little curious that attempts to preserve it from the slow destruction of the former of these have been the first to engage the attention of mankind, while to immunity from the rapid and fearful effects of the latter there has hardly been given a thought. Perhaps we may find a solution to this in the fact that from the earliest ages mankind seem to have been impressed with the idea that wood in buildings, when once ignited, must continue to burn until it is extinguished by the opposite element. Hence we find at an early day in the history of large towns and cities, that some rude methods were adopted for this purpose, and reservoirs for collecting and preserving water were contrived and used. But perhaps the universal impression that wood must be kept and continued combustible in order to be used as fuel, for warmth, for light, and for cooking, may have had something to do with this apathy in rendering it incombustible. The discovery of coal is quite modern, and that of mineral oil, and the illuminating and heating properties of other hydro-carbons, still more so. Therefore, let it be understood that in all our successful means of rendering wood incombustible, enough must be left in its natural state to kindle our coal fires.

Nearly all fires originate in one or more of the following causes: Electricity, spontaneous combustion, friction, carelessness in handling or controlling the element, and incendiarism.

No disastrous fire can be kindled where there is no wood that is combustible in the building in which it originates! To render any fire injurious to a great extent, it must have a certain amount of atmospheric air, and this produces a flame. A fire may smoulder for an almost indefinite length of time, in certain combustible materials, engendering gases, but it assumes a dangerous condition only, when, by a supply of air, it bursts into a flame. If any method can be devised to prevent this flame where there is no explosive material, not one building in five thousand could be destroyed. As stone, iron, brick, and plaster will not of themselves ignite, there is only one building material to guard against, and that is wood. But, unfortunately, wood is the very material which is, and must be, used to a great extent in the construction of the interior of our buildings. The doors, window-frames, and casings, the floors, base, ceilings, lathwork, and nearly all our furniture, are formed of some kind of wood.

The wood once kindled into a flame, and this flame allowed to get headway, our plaster partitions, our solid stone or brick walls, and iron, tile, or slate roofs rapidly melt, disintegrate, and give way under the intense heat. A common fire in a grate or fireplace gives but about 800 deg. of heat, but, increasing in intensity as it gains in volume, it soon rises to 1,070, which heats iron to redness, and this communicates instantaneous flame to wood or other combustible matter, and at 2,754 deg. iron melts, and granite disintegrates and crumbles to atoms.

Perhaps in the general use of stone,

brick, iron, and plaster, the city of London is as securely built as any city in the world, unless we except Paris and Florence. But we have no better standard by which to judge of the security of our city and its presumed exemption from the destructive element, than the experienced judgment of its inhabitants, as proved by the amount of money they are willing to pay yearly for a partial exemption from this loss. The amount of property insured during the past year by 52 fire insurance companies in the city of London, as we learn from the Law Fire Insurance Society's Almanac for 1873, was £463,235,000 sterling. The amount paid on this, at the medium rate of premium of 28s. on £1,000, was £16,544,000.

Now, what is the nature of an insurance against fire? It is merely a contract by an individnal with a company to share with such company a portion of his loss by fire, for doing which the individual pays to the company a certain sum in cash in advance, which thus for a time, and to a specified amount, becomes a partner in any loss by fire which may occur on the premises during one year. If a fire does not occur during the year, the amount thus paid is a clear gain to the insurers and a dead loss to the insured, except in the feeling of safety and content which the consciousness of such bargain must give, a feeling which, perhaps, fully repays the insured, for no prudent man will allow valuable property to go uninsured. Insurance companies, then, are a necessity and a blessing; but can none of the calamities and losses by fire be mitigated or diminished? It may be possible to ascertain exactly what has been the real loss of property in the City of London, and even in the whole of Great Britain, during the past ten years by fire, but I have not been able to get figures sufficiently accurate to put before you. At all events the amount must be very large. I happen to know what it has been during the last two years in the United States of America, including the Chicago and Boston fires, and it amounts to something over £55,000,000 sterling, or more than 275,000,000 dollars. This is a low estimate of the money value, to which must be added the loss of human life and the human suffering.

There are many substances which may be used to render cotton or linen fabrics partially or wholly incombustible for a period of time, but recently the tungstate of soda has been most frequently applied in a liquid state for this purpose. An external wash of minerals mixed with clay, lime, and charcoal, has been applied to rough-wood work, and this for a season will effect the object. But none of these, nor the manner of applying them, satisfactorily answers the great question—Can all kinds of timber for ship-building, beams for house-carpentry, and the finishing of dwellings, warehouses, and stores, and wood furniture, be rendered incombustible on a large scale, so cheaply as to render the use of such wood and lumber economical for the ten thousand purposes to which it is applied? No superficial application, no washing over after the work is finished, no painting, will answer this universal want. The nature of the wood must be changed at a period when it is capable of being permeated with a liquid, vapor or steam, that will effectually and for ever prevent such wood from becoming inflammable. It is not possible, nor is it necessary, to prevent wood from carbonizing when exposed to a high degree of heat. But if it can be so prepared that it will not break out into a flame, the object will be obtained, for no fire can ever be made extensively or rapidly destructive unless by actual flame, which spreads the element to all combustible material that it meets with.

As I have said before, there are many methods (some of them secured by patents) to render timber indestructible by time, especially the timber of piles for wharfing and foundations, or of railway-sleepers and cross-ties for telegraph poles, etc. Many, and perhaps all these methods have been, and will continue to be, successful. But it is known to all of you, probably, that the material applied for this purpose only penetrates the timber a trifle beyond the surface, deeper, however, at the ends than the sides of the timber, and is always applied after the wood is fitted for use. Heated coal-tar, resin, or other hydrocarbons, are the subtances generally made use of, and these will, if properly prepared, prevent moisture from penetrating; but we must remember that all hydrocarbons are much more inflammable than dry wood itself, and therefore nothing of this kind will avail us in rendering wood incombustible. We are now again brought round to the recurring question,—Can all kinds and qualities of wood be cheaply rendered incombustible before they are sawed up into the various shapes and sizes in which we find them in

our timber and lumber yards? After many years of investigation and experimental labor, I now think this question may be answered in the affirmative.

Nearly all the vegetable world draws most of its moisture from the earth. The "pores" of wood, as they are usually called, carry up at certain seasons of the year nearly pure water from the roots, through the body and branches, to the new shoots and leaves. Under the power of the microscope, these pores or tubes, in some trees to the number of a million to the square inch, can be traced in a continued unbroken series, conveying the moisture, by capillary attraction and the natural laws of heat and evaporation, upwards and downwards through the trunk of the tree, adding a ring or circle of growth for every year of age in all the various woods of which we make use for building and other purposes.

When the tree, taken in its live and growing state, is cut down, the process of evaporation or seasoning commences. At this time all the pores of the tree are distended, and at certain seasons are full of sap. To expel this sap from the pores while the log is in its natural state, and to introduce the substance which will render the wood for ever incombustible, is now the desideratum.

All timber in seasoning "shrinks," or is contracted. This is entirely owing to the expulsion of the water from the sap-tubes, and the consequent contraction of the walls of these tubes. Now, when the water is expelled by evaporation, if it has contained any substance held in solution, a portion of that substance will be left as a deposit upon the walls of these sap tubes or cells. If this substance is of an incombustible nature, although it were so thin as to be invisible to the naked eye, yet, as it is equally spread upon both sides of each partition of the tubes or cells, it renders the entire log, and consequently every plank, board, or lath cut from the log, incombustible.

It will be apparent to all, then, that after the sap-tubes have been emptied of the moisture which has been the sustaining aliment of the tree, and they have collapsed, or nearly closed up, no immersion in liquid, even though it should be kept at boiling point for an indefinite length of time, will thoroughly and uniformly permeate the wood so that the centre of a log or plank will be as perfectly saturated as the outside.

The following is the manner which I have adopted for the purpose of expelling the natural sap or moisture from the green timber, and introducing the liquid which will render such timber for ever after incombustible. At an elevation of about 40 ft. above the log, I have a reservoir containing, say, 500 gallons, with a depth of liquid of at least 8 ft. From this reservoir a 2-in. pipe descends perpendicular to the log. The log, which is double the length of the boards intended to be cut, is sawed nearly in two, transversely, at its centre, leaving a strong "curb" or joining piece on the underside—not cut through. By raising the centre with wedges, or a screw, this transverse cut will be opened, mostly at the top, but partially down to the bottom. Into the cut I introduce a cord or wire, prepared for the purpose, and lay it around the cut just inside the bark of the log, bringing the ends together, to meet at the top. Now, by removing the wedges, or turning the screw down, the two ends of the log will close again tightly, with the exception of perhaps a sixteenth of an inch, according to the size of the cord or wire, which is held so tight as to prevent the escape of any liquid.

I then bore a hole on the top of one of the logs, towards the cut, at an angle of 45 deg., so that it will fit just into the cut, and into this I introduce the bottom of the vertical tube, which is connected with the reservoir above, the tube being diminished in size at the bottom to allow it to fit tightly into the bore, which reaches the cut just inside the cord at the top. When ready, I open the stopcock at the top of the tube, and allow the full pressure of the 40 ft. of liquid to flow into the pipe. The space at the ends of the two logs is instantly filled, and the pressure is very great, forcing the liquid into every pore of the timber each way alike. In a short time the natural sap is forced out of the ends of the log, and is followed by the prepared liquid, which is equally limpid. As soon as the latter begins to appear at the ends, a process which takes but a few hours, the process is ended, the preparation is shut off, the logs are divided, and are then ready to be sawed into boards, joists, laths, etc., and the stuff will season in the usual way. The weight of the timber is very little increased as compared with other stuff not prepared. But the whole of the timber is thus permeated from centre to circumference, and will not blaze at any amount of heat to which it may be exposed.

I have thus adopted a method by which, without the use of steam or machinery, a powerful agent can be brought to effect the dislodgement of the natural sap, throughout an entire tree, however large (and perhaps the larger the better), when cut into sections, while by the same power, and in a few hours, I supply its place by filling the pores or tubes with a prepared liquid, which will render the wood incombustible without changing its color, strength, or softness. I have been asked what effect this process will have upon the durability of timber. I cannot say that it would last forever, but we have the strongest reasons for believing that it will protect from all decay by moisture, fungus, or salt water. Of one thing I am certain—timber prepared in this way will never be attacked by worms or borers; and the white ant, so destructive to timber in warm climates, will not touch it. The importance of this, in relation to shipbuilding, is second only to that of the impossibility of its destruction by fire.

One of the shrewdest of journalists, a man of world-wide fame, who has just passed away, said, more than thirty years ago, that there were three great desiderata in the civilized world which he hoped to live long enough to see accomplished. The first was, the connection of England and America by telegraph wires under the ocean; the second, the utilizing of the waste screenings and dust of mineral coal; and the third, the rendering ship and building timber of all kinds incombustible. He did live to see the two first wishes realized. Can it be that the last is not within the power of man to accomplish? Because a thing has not been done, is that a valid reason that it never can be? Would such a deduction be in accordance with the spirit of the age?

There are three substances which, combined in proper proportions, will accomplish this object. As I have said, however, seasoned wood of any kind cannot, for the reasons mentioned, be made indestructible by fire. The external surface may to a certain extent be rendered incombustible. Seasoned wood can only be affected by immersion, and that only partially, as a few specimens which I have here will show you. Please bear in mind that any wood, even if fully prepared, can, when steadily exposed to a high heat, be carbonized, changed into charcoal; but if it cannot be fanned into a flame, if the introduction of air will not cause it to break out into a blaze, no danger need be apprehended from it; even incendiarism, the worst and most revolting of all crimes, cannot fire a dwelling, a warehouse, or a ship; and is it not worth all the time and expense it may cost in introducing such an improvement when we remember the vast amount of life, property, and suffering it must save? In relation to the expense of the process, I believe, after much inquiry as to material, etc., that on a large scale all woods may be rendered incombustible by an increase of not over 20 per cent. on the ordinary price of the same timber and lumber in its natural state, perhaps for much less than this. As I do not come before you with a patent, I trust I shall be excused my omission of any further detail of the process, and the more inasmuch as it would be hardly possible for any individual to properly test the process without some of the experience and outlay to which I have myself been subjected. I shall, however, be glad to confer with any gentleman who may see in this improvement great benefits to commerce and the building art, and a new means of preventing the loss of human life.

ON THE USE OF HIGH PRESSURE STEAM.*

From "Engineering."

There is no subject of greater importance for the civilized world at large than the determination of the pressure at which steam can be used with the greatest economy. The quantity of coal used in producing steam power is so great that a small fraction of its annual value would amply repay any possible expense that could be incurred in making experiments.

And yet, great as would be the saving of even 1 per cent. of the coal burnt, we do not find that any systematic attempts have been made to ascertain what, for ordinary purposes, will be the most economical pressure at which steam can be used. By

*Paper read before the Manchester Association of Employers, Foremen Engineers, and Draughtsmen. By Prof. OSBORNE REYNOLDS.

the most economical pressure, I do not mean simply that which will give us the greatest amount of work for the coal burnt, but that which will allow an engine to be worked at the least expense, including its first cost, and every expense connected with it.

There seems to be at the present time a very general belief that economy is only a question of pressure; that it may be insured by working at a high pressure of steam; that, in fact, the greater the pressure, the greater the economy.

Now if this assumption is correct, it is strange that there is not more advance made towards the use of steam at high pressures; for the idea seems to be firmly impressed on the minds of most engineers. This may, no doubt, be to a certain extent explained, by the necessary time required to effect any change, where there is so much capital, and such a number of people interested in maintaining the existing state of affairs. But there is something more than this, for the question has been agitated now for many years; and many of the facts that are brought up over and over again as new were well known in Watt's time. For my own part, I do not doubt that Watt had as clear a perception of the advantage of using steam at high pressures as we have, although the theory of steam and heat engines was not so clearly understood in his time.

Nor do the practical difficulties in the way of using steam at high pressures, such as the construction of boilers, the packing of glands, etc., appear to be a sufficient cause why it has not been done. There must be many present who have a great deal of experience in the use of steam, and I hope to hear from some of them what are these practical difficulties; for my own part, I have never come across them. I do not mean to say that an engine which has been designed, or even improved by experience, to work at 20 lbs., can be easily modified so as to work at 60 lbs. Of course there would be many things to learn by experience, and hence we must expect failure at first; but I cannot see any difficulty in constructing an engine which shall work at 300 lbs. pressure as safely as is now done at 50 lbs.

To pressures higher than 300 lbs., I admit, we cannot go, for the temperature then becomes such that no lubricant will remain in the cylinders or on the valve faces; tallow will boil at 500 deg. F., *i. e.*, the temperature of steam at 325 lbs. pressure. Even at lower temperatures than this, tallow will dry up to some extent.

Assuming then, as I do, that the mechanical difficulties in the way of using steam at pressures up to 300 lbs. can be overcome, the next question is—what advantage will be derived from the use of steam at such pressures? In the first place, can we save coal? and in the next place, shall we have to incur any increase in the expense of constructing and maintaining our machinery?

This is a question which may now be very well answered, without any further experiments. Owing to the researches of Regnault, Rankine, Fairbairn, and others, we have sufficient information for the solution of all questions which can occur with regard to the use of steam under these heads.

In considering the economy of different steam engines we shall do well to divide the engines into *three* parts. First, the boilers; second, the cylinder and pistons; third, the mechanism of the engine. Now, with regard to the first and last of these, it is not my intention to say much to-night. I suppose all the steam furnished by a good boiler, and that 1 lb. of coal will send as much heat into the boiler at 300 lbs. pressure as into that at 20 lbs.; though whether this can be done or not is a question which will bear experiments. Such, then, seems to me to be the state of the case, supposing that steam can be supplied at the high pressures as economically as at the low. In certain cases, as where salt water is used, we know this cannot be done, and it may be that we have yet to learn, by experience, whether the extreme pressures will produce any physical effect with which we are as yet unacquainted, and I am not without hope that some present may have experience in the use of high pressures which will help us on this point. As far as I can make out, there is no reason to suppose that it would not, if due care was taken to introduce the cold water in an economical manner. I assume, then, that a pound of coal will send as much heat into a boiler as will raise 10 lbs. of water from 32 deg. to 212 deg., and convert it into steam at 212 deg. This would be done in a first-class boiler, but not in a locomotive boiler; in such the evaporative power would be about 7 lbs. Very well, then, giving the engine the advantage of a good boiler, we proceed to consider how much work 1 lb. of coal will do. Here again, I shall take what is called the

indicated HP., that is to say, the work which the engine would do suppose it were frictionless.

In a cylinder which is not protected with a steam jacket, there will be condensation, which produces a great loss of work from the effect it has in cooling the cylinder during the exhaust; such loss cannot well be taken into account, and in every good steam engine will be prevented, either by the use of the jacket, or by superheating the steam, or else by wire-drawing the steam before it is used, which has the same effect as superheating it. I have, then, assumed that the steam is to be kept dry by some such process.

On these assumptions I have constructed the following table, in which the numbers have been deduced from the tables of Regnault and Rankine by approximate methods. The object of these tables is to show, first, the relative consumption of coal at different pressures, ranging from 20 to 300 lbs., for three different classes of engines.

TABLE *showing the Relative Economy as regards*—1, *Consumption of Coal;* 2, *Size of Cylinders;* 3, *Strength of Piston Rods; for Non-condensing, Condensing and Compound Engines, working at Various Pressures. The steam is to be supplied from a First-class Boiler, in which* 1 *lb. of Coal will raise* 10 *lbs. of Water from* 32° *and convert it into Steam at* 212°. *The Cylinders are supposed to be kept dry by a Steam Jacket or otherwise. The speed of Piston is assumed to be* 500 *ft. per minute.*

	Non-condensing. No Expansion. Back Pressure =15 lbs. per square inch.				Expanding to 5 lbs. above atmosphere. Back Pressure=15 lbs.				Expanding to 10 lbs. below atmosphere. Back Pressure 5 lbs.				
Absolute pressure.	60	115	225	305	60	115	225	305	29	60	115	225	305
Pressure above atmosphere	45	100	210	290	45	100	210	290	14	45	100	210	290
	Ratio of Expansion				3	5·75	12·5	15	5·75	12	23	45	61
COAL: Per HP. per hour.	4.83	3·81	3.55	3.44	2.80	1.75	1.24	1.08	1.60	1.17	.95	.82	.73
CYLINDER ROOM: Per HP. in cubic ft. per minute..	5.30	2.50	1.10	.80	8.50	5·70	4.25	3.75	21.30	15.60	12.80	11.20	10·37
CYLINDER ROOM: For Compound Engines	..	..	..	..	10·50	8.10	5.50	4.75	30.10	20·00	15·40	12.80	11.60
PRESSURE ON PISTON: For one Cylinder..	64	64	64	64	107	159	255	304	153	248	390	696	876
For two Cylinders	32	32	32	32	53	80	128	152	76	124	198	348	438
For Compound Cylinder.....	..	..	..	..	61	66	76	80	63	71	83	104	112

1. Non-condensing engines, but with a fixed rate of expansion—a fixed cut-off. Since the relative economy for different pressures will be independent of the actual cut-off, so long as it is the same at all pressures, the table has been calculated for a full cylinder. In this table we see that the coal, per horse power per minute, with a pressure of 45 is $\frac{1}{5}$=20 per cent. more than with a pressure of 100, but that after this there is comparatively little advantage in the use of a higher pressure, there being only 10 per cent. gain from 100 to 300. What then becomes of the advantage of the use of high pressures in this class of engine which may be called the locomotive

type? It agrees very well with the fact that in locomotives, pressures of about 120 lbs. are generally used.

2. In engines in which the rate of expansion is such that the steam is always discharged at a fixed pressure, for example, 5 lbs. above the atmosphere. In this case the rate of expansion will depend on the initial pressure of steam. This is shown in Table II. Here we see that from 45 to 100 there is a gain of 39 per cent. and a gain of 29 per cent. from 100 to 200, while there is only 15 per cent. from 200 to 300. Hence the greatest gain is from 45 to 100, but there is a considerable advantage in going higher.

It will be found in this class of engine that it is the rate of expansion that determines the economy of the engine, that is to say, the higher the expansion the higher the economy. Now, the rate of expansion will depend on the difference between the first and last pressures. Hence the greater this difference the greater will be the economy. This class of engines is typical of ordinary mill engines and others in which the blast is not wanted up the chimney.

By condensing the steam we can work with a greater rate of expansion at the same pressure, and hence we have greater economy. Thus if we expand down to 10 lbs. below the atmosphere, with an initial pressure of 45 lbs., instead of a cut-off of $\frac{1}{3}$ we get a cut-off of $\frac{1}{12}$, and the coal is diminished by 60 per cent. From Table III. we see that the coal diminishes much as in Table II., quickly from 14 to 100 by about 40 per cent., and then slower, only by 20 per cent. from 100 to 300.

So much, then, for the coal. We see that when a high degree of expansion can be used there is considerable gain in increasing the pressure, but not so much after 100 lbs. for non-condensing and 60 lbs. for condensing.

The second thing which the tables show is the inconvenience of high rates of expansion. We see in the two next columns the quantity of cylinder room that must be provided per minute per horse power, and if we divide these figures by the speed of the piston in feet per minute, we shall have the areas of piston. The compound cylinders are supposed to be so adjusted that the work done in each cylinder equals half the whole work, *i. e.*, the expansion in the first cylinder equals the expansion in the second. This rule will not be quite accurate, but nearly; I do not know that there is any rule in practice. The difference in cylinder room, it must be noticed, is very much in favor of high pressures, as it diminishes in each case as the pressure increases. Thus the area of piston required at 300 lbs. is only half that required at 20 lbs. pressure in a condensing engine. And it is to be noticed that in the compound engines the necessary increase is much smaller for high pressures than for the low pressures. At 20 lbs. the high-pressure cylinder has half the area of the low-pressure cylinder, whilst at 300 lbs. it has only about $\frac{1}{12}$.

Now as regards the strength of the engine. This is the great objection to the use of high rates of expansion. It will be seen from the table what must be the relative strength of the piston rods for the various engines at different pressures; for a fixed ratio of expansion the pressure makes no difference, but with the second and third classes we see that this pressure increases enormously, in the last case from 153 to 876, or nearly seven times; that is to say, the machinery of an engine to work at 300 lbs. must, only to do the same work, be seven times as strong as that which works at 20 lbs. Here, then, is a fatal objection against the use of steam at high pressures, unless it can be met in some way. This is where the advantage of compound engines comes in. In the last row of the table is shown the greatest pressure on each piston if the engines are compound, and above are the same for an engine with two cylinders not high and low. Comparing these, we see that while the pressure in the one increases from 76 to 438, the other increases from 63 to 112. Thus by the use of compound engines the pressure on the pistons can be kept quite within reason.

To sum up, then. By the use of steam at 100 lbs. we may do with little more than half the coal required for a pressure of 14 lbs., with only three-quarters the cylinder room, and shall only increase the greatest pressure on the piston by about 10 per cent. With 300 lbs. we do with 20 per cent. less coal than at 100 lbs., two-thirds the cylinder room, and must increase the strength of the machinery by 40 per cent.

I think, then, that this table shows clearly in which direction we must look for economy, namely, by increasing the ratio of expansion and the use of high pressure steam so far, and only so far, as is necessary for the expansion for engines in which

the release takes place at or below the pressure of the atmosphere. There will be advantage in pressures at least up to 120 or 130 lbs. Beyond this it must be a question for experience to decide how high we shall go.

In such engines as use a blast we shall find that there is great economy in using very high pressures of steam, provided the rate of expansion is increased. Thus, in a locomotive in which the blast was fixed at 30 lbs., it would be much more economical to use steam at 200 lbs. and expand four times, than at 100 lbs. and expand twice, and the blast would be much the same.

SHIPS FOR THE CHANNEL PASSAGE.*

From the "Journal of the Society of Arts."

I believe that the object of the Council of the Society of Arts, in asking me to read a paper on this subject, is that of promoting public discussion of it. They did not, I hope, expect that I should be able to throw any original light on it. Nor, were I able —which I certainly am not—should I attempt to do so on this occasion. My efforts will be directed chiefly to bringing together the various methods which are about to be tried practically of giving increased comfort to those who have to cross the Channel, in order that the promoters of each may, if so minded, help us to compare them impartially, and thus both prepare the public mind for a new state of things, and also themselves derive possibly some of those advantages which are generally found to follow open debate.

I need say very little to persuade you that there is room for improvement in our present means of crossing the Channel. The sum of human misory accumulated in a generation by the horrors of that short voyage, is beyond calculation and beyond words. When a boy at school, some forty years ago, my parents lived on the Continent, and I had to cross frequently every year for my holidays. After leaving school, I spent twenty-six years in India. When I returned to Europe, I found the Channel steamers almost exactly what I remembered them in my youth—improved, no doubt, in speed, but in nothing else worth mentioning. The same cockle-shell tossing about, the same pitiless deck exposure, the same fetid cabin atmosphere, the same utter absence of special accommodation fit for those willing to pay for it, the same disgusting filth and brutal disregard of the commonest decencies; and all these evils in kind, far from having undergone mitigation in degree, absolutely aggravated by the crowding of passengers, baggage, and goods, which the railway system has, since I was a boy, poured into these vile floating receptacles.

I should qualify the very strong expressions I have here used by acknowledging that some little effort has recently been made to improve existing Channel steamers. In the autumn, the Albert Edward, belonging to the South Eastern Railway Company, had a little awning spread over the deck, which is, so far as it goes, an improvement, but it is very slight.

It is, perhaps, known to many of the audience that a committee of this Society, of which our gallant chairman is a member, has been for some time accumulating evidence on the subject of the Channel passage, which has been published in the "Journal" of the Society. While this evidence exhibits much diversity of opinion on the numerous remedial measures proposed, nothing is more striking than the general consent of impartial witnesses as to the main cause that has retarded improvement —namely, the refusal of the railway companies to consider anything but the question of dividends—and to reject any scheme for substantially increasing the comfort of the public, to whom they owe their privileges and very existence, if it threatened any immediate expenditure, however great the prospective gain by increasing passenger traffic, might promise to be. I do not intend to dwell on this unquestionable fact. But, speaking on the Channel passage, it is not out of place that I should record, in connection with it, one of the numerous instances in which our gigantic private railway monopolies have signally failed to fulfil their obligations to the public—failures which, affecting safety to life as well as comfort and convenience, have now produced a

* A paper read before the Society of Arts, by Lieut. Col. A. STRANGE.

strong body of opinion favorable to the transfer of railways to the State. I shall merely add, that for the contrivances for improving the Channel passage, forming the subject of this paper, we are indebted, I believe, solely to private enterprise and individual invention, and in no degree whatever to the initiative or encouragement of the various railway companies who have so long supinely permitted us to suffer such grievous misery.

A few introductory words on the subject of sea-sickness seem necessary in order to estimate properly the various expedients by which it is proposed to mitigate or prevent it. I am not a physiologist, and shall, therefore, not presume to dogmatize on a malady, the causes of which are, I believe, to some extent in dispute amongst physiologists themselves. A distinguished surgeon, whose opinion I recently consulted for the purpose of this paper, told me that he believed the main cause to be the forcing back of the blood upon the cerebellum, that part of the brain in immediate connection with the spinal column, through which the abnormal disturbance was communicated to the stomach and other organs. My learned friend did not adopt the more popular explanation that the mechanical pressure of the diaphragm was the chief cause of sea-sickness, and he gave me his reasons for holding the above views, which I fear to repeat, lest, in my ignorance, I should misstate them. The brain theory, as I may call it, certainly seems supported by the fact of the well-known intense mental prostration and distress which is a peculiar feature of sea-sickness. Others attach some importance to optical causes, and believe that the sight of swinging objects in motion helps to aggregate, if not to produce, the malady. I once tried an experiment, which, from its bearing on this supposed cause, I may briefly describe.

Some years ago I was about to cross, in an open boat, the harbor of Kurrachee, in Scinde, to Manora-point, on which the lighthouse stands. A lady, who was of the party, announced that she should be sick directly the boat was pushed off. I suddenly remembered, in this emergency, having read of a mode of preventing sea-sickness, which, although I felt no faith in it, I thought worth trying. It consisted in giving the lady a tumbler nearly full of water, which she was to keep steady so as to spill none of its contents. She followed my instructions, and at the end of our passage, which only occupied a few minutes, she declared that for the first time in her life, under similar circumstances, she had experienced no uneasiness whatever. The explanation is probably that of illusion caused by the quiescence in the tumbler of water. Though such an illusion can hardly be expected to be of long duration, even if the experiment could be continued, it yet seems to indicate that any means which can be adopted to cheat the mind into thinking that the ship is not in motion, may be serviceable.

But, whether the disturbance of the victim be of a functional, mechanical, or mental kind, or of all combined, no doubt can exist that as a whole it is caused mainly and primarily by the motions of the vessel. Let us, therefor, consider what these motions are. They are principally of two kinds—angular and rectilinear. The angular motions are:—1. Pitching. 2. Rolling. 3. Horizontal or azimuthal swaying.

The rectilinear motions are: 4. The longitudinal advance of the ship on her course. 5. Lateral drifting. 6. Upward and downward motion of translation.

Besides these motions there are others affecting, not the ship as a whole, but her structure. Such as, 7, Temporary vibration caused by the concussion of waves, and 8, Continuous tremor caused by the working of her engines—if a steamer.

We shall be able at once to eliminate several of these motions, and so materially reduce the number that have to be counteracted.

No. 4, The longitudinal advance of the ship, may be set aside, first, because if we are to get across the Channel at all we cannot dispense with it; and, secondly, because our experience of it in land travelling proves that it has nothing to do with causing sickness. No. 5, Lateral drifting, being a motion precisely the same in kind, though much less in degree, can have still less to do with the matter. In an omnibus, for instance, we are subjected to this lateral motion without bad effect. No. 3, Horizontal or azimuthal swaying, must produce the same effect as No. 5, Lateral drifting—that is, no effect at all.

Leaving the effects of Nos. 7 and 8, Vibration and Tremor, respectively, to be considered at a later period, we come now to No. 6, Upward and downward motion

of translation, which requires careful consideration. The usual definition of motion of translation is that it is the motion of a body advancing continuously or oscillating backwards and forwards in a direction parallel to itself. The solar system, though composed of planets rotating on their respective axes, and revolving in nearly circular orbits, has also a bodily progressive motion in space sensibly rectilinear in direction. This bodily movement, which is quite distinct from the others—is a motion of translation. The piston of a fixed steam-engine has a vertical motion of translation. upwards and downwards within the cylinder. In this case there is no other motion to complicate or mask that of translation. An example of rectilinear motion of translation, combined with angular motion, is afforded by the piston of steam-engines with oscillating cylinders, such as are generally employed for marine purposes, and to be seen in all the penny steamers plying on the Thames. In this we have the motion of translation of the piston up and down in the cylinder, as in the fixed engine, but its inclination with respect to the horizon is, at the same time, constantly varying with the oscillation of the cylinder along which it moves. Bring the angular oscillation of the cylinder to a standstill, and we have only the rectilinear motion left, as in the fixed engine.

In a ship we have the same movements as in an oscillating engine cylinder—the varying angular inclination caused by pitching or rolling, whichever we may be considering, and the rectilinear translation caused by the heaving of the waves up and down vertically. This may, perhaps, be even more clearly illustrated by means of the beam of a Cornish pumping-engine. As always made, the beam possesses longitudinal angular motion only, analogous to the pitching of a ship. But let us imagine the centre or point on which the beam turns to be placed at the top of a piston-rod working up and down vertically in a cylinder. This would give to the beam translatory motion in addition to the angular motion. Further, let us suppose the centre or joint, instead of acting in one plane only, to have a rocking motion at right angles to the length of the beam, then that would represent the rolling of the ship, and we should thus have all three motions—pitching, rolling, and translation, acting on one and the same beam, simultaneously, as in a ship.

No proposal has yet been made for getting rid of the vertical translatory motions of ships, nor is it conceivable how this can be done. I have, however, dwelt upon it, because much confusion of thought exists regarding this particular motion, as to which I may have more to say presently.

We have now reduced the motions to which a ship, as a whole, is subject, to two of our list, namely, No. 1, Pitching, and No. 2, Rolling. I shall now proceed to examine the various projects which have been made public for reducing or preventing these two motions. Of all the projects now before the public none attempt to deal with more than the two motions.

I believe one of the first in order of time is that of Mr. Sedley, a model of which is now before you. The basis of Mr. Sedley's construction is identical with that of Captain Dicey; and as I understand these two inventors, instead of opposing each other, have judiciously entered into alliance, I shall presently consider them together. Another plan was put forward by Mr. Mackie some time ago. I made a cursory examination of his model, exhibited at one of the soirées of the President of the Royal Society. The impression left on my mind being rather vague, I expressed a wish to make a comparative examination of Mr. Mackie's and Captain Dicey's model in these rooms, side by side, before writing my present paper. Bnt this was not agreeable to Mr. Mackie, and I am still a good deal in the dark about his ship, and cannot safely attempt a description of it. This is, however, at present of the less importance that no steps have yet, I understand, been taken to bring his principles to the test of commercial application. I believe, however, that Mr. Mackie proposes to reduce the motions of the ship more by her dimensions than by any special peculiarity of form; and we all know the influence of size in this matter, other things being equal.

I now come to the Sedley-Dicey ship. She also is to be much larger than the present Channel ships. The dimensions given by Captain Dicey are 400 ft. length, and, as I understand him, 75 ft. beam over all. Possibly these figures have since been modified, but it is more with the principle than the size, though that is important, that I am at present immediately concerned. The principle is avowedly borrowed from the native boats to be found at Ceylon and on the western coast of India. These have two

long beams fastened firmly athwart ships, and projecting many feet on one side. To the extreme external ends of these beams is fastened a log of wood or outrigger parallel to the boat. When the wind is on the outrigger side, this beam, acting as a counterpoise at the end of a long lever, prevents the boat being capsized on the opposite side. When the wind is on the boat side, the outrigger acts as a supporting or resisting float, and prevents the boat capsizing towards it. These boats are well known for their safety in a sea which without the outrigger would swamp them, and they are said to have much less rolling motion than ordinary boats of even much larger size. They carry a very wide spread of canvas.

Captain Dicey's arrangements for carrying out this principle on a large scale may be thus described: Let us imagine a ship 400 ft. long, and 40 ft. beam, divided right through from end to end in the direction of her length, and let us suppose the interior sides of the two halves thus exposed and open to be covered in with wood or iron; these interior sides of the two halves would then be quite flat and their exterior sides would be of the original form of the ship. Now let the two halves be separated until the two interior sides are 35 ft. apart from end to end. Next let a continuous bridge of iron girders be made to span and firmly connect these two halves. We should thus have obtained an area for deck and saloon and cabin accommodation 400 ft. long, and 75 ft. across at its widest part. The engines are to be amidships, and the paddles, two in number, are to work in the space between the two half-ships. You will observe that Mr. Sedley's model, now before you, resembles what I have briefly described, except with regard to the paddles, which he places outside the half-ships. This, of course, gives him less space for entering harbors. Which position of the paddles is best for speed, is a question, I believe, still to be decided. Captain Dicey proposes to have rudders at either extremity of both half-ships, to obviate the necessity for turning in harbor, which would, in some cases, be impossible with such long ships. The pair of rudders in actual use, will, of course be geared together. Capt. Dicey estimates the draught of water of a ship of the foregoing dimensions to be only 6 ft., which will admit of her entering existing harbors on both sides of the Channel.

It is evident that Capt. Dicey aims at mitigating only two motions to which ships are subject, namely, pitching, by great length and possibly peculiar form of bow; and rolling, by abnormal extent of beam. The motion of translation, whatever it may amount to, will be of the whole amount due to a ship of the intended size and immersion. Capt. Dicey's plan may, therefore, be described as aiming at its object by means of external form only.

I come now to Mr. Bessemer's plan for diminishing a ship's motion. This constitutes as great a departure from ordinary usage as Capt. Dicey's, and is probably even more original. The ship, which is the design of Mr. E. J. Reed, C. B., late Chief Constructor to the Navy, is to be 350 ft. long, with a beam of 45 ft., and she is estimated to draw 7 ft. 6 in. of water, which is the same as the draught of existing Channel steamers. The two chief aims of her external form are high speed and diminished pitching. As to the first, I need only say that there is nothing to prevent the concentration of every known expedient, so far as form is concerned, for attaining this object. It is intended to reduce pitching to a minimum by giving to the bows a form such as will cause the ship rather to cleave through the waves than rise to them or over them.

It is for the diminution of rolling that Mr. Bessemer, like Captain Dicey, has introduced novel arrangements. Mr. Bessemer's suspended saloon has already been very frequently described, but my paper would be incomplete if it did not explain the main features of this remarkable invention.

The saloon for a ship the size I have mentioned, will be 70 long, 35 ft. wide, and 20 ft. high. It will be placed in the middle of the ship. Instead of being an immovable section of the ship, it will be a distinct structure, supported at its two ends by cylindrical pivots, resting on supports firmly connected with the body of the ship, the line joining the two pivots being parallel to the ship's keel. These pivots being placed a little above the centre of gravity of the whole mass, the saloon will be free to adjust itself to the horizontal position, however much the ship may lean over. So far there is no novelty of principle, though perhaps this is the largest structure ever so suspended. The hammock and swinging cot are on the same principle. And such a

suspension would entirely fulfil its purpose but for three disturbing influences—namely, 1. The action of the wind on the outside of the saloon. 2. The shifting about of the weight of the large number of passengers it will accommodate; and, 3. The effect of the ship's own movements.

The first two disturbing causes are too obvious to require more than naming. The third needs some explanation. A box chronometer and a binnacle compass are suspended in a manner even more complete than, but still similar to, Mr. Bessemer's saloon. If we place a binnacle compass in its box on the table, and gently tilt the box, we shall find that the compass preserves perfectly its horizontal position. If we now walk quickly with the box about the room, or wave it to and fro, tilting it at the same time, we shall find that although the compass preserves generally its horizontality, yet it is never quite quiescent, but sways backwards and forwards, to an extent less than the tilting perhaps, but still quite appreciable, and varying with the suddenness and velocity with which we wave or carry about the box. This arises from the inertia of the suspended compass preventing its at once adapting itself to the rapidly changed position of the point of suspension. It first lags behind its true position, and then is carried by its own momentum beyond it. In this way swaying motions are communicated to the compass, known as secondary oscillations. Any suspended body is subject to the same phenomenon—amongst others, the pendulums of large clocks, which, if not suspended from a very firm support, will have secondary oscillations very destructive to accurate time-keeping.

Sir John Herschel endeavored to counteract this motion in the case of a swinging cot by introducing certain arrangements. His invention, described in the "Journal" of this Society, displays the ability you might expect from a man of his genius, and no doubt it is very fairly effective in the case of a cot and diminishes the swaying motion. But it would not be applicable to so large a structure as a saloon, nor will it fulfil the intention as fully as Mr. Bessemer's invention pretends to do.

The peculiarity in Mr. Bessemer's suspension, which distinguishes it from all others, consists in appliances for controlling the three disturbing agencies I have mentioned, whilst giving the suspended body entire freedom to assume a generally horizontal position. There are many modes of doing this which might be more or less effectual. Ropes passing over pulleys and worked by windlasses by manual power, or lateral pressure-screws, might be applied with some effect. The plan adopted by Mr. Bessemer differs entirely from these. It would occupy too much of my space to describe it in detail—nor could I expect to make all its parts intelligible without a number of drawings and models, such as could not be studied with advantage by a public meeting. The following general account, furnished by the designer, and quoted in an able article, by Mr. Merrifield, in the January number of the "Popular Journal of Science," may suffice for present purposes:—"A toothed sector, of large diameter, is secured to the main central axis of the saloon structure, and beneath it is a strong bed-plate firmly attached to the floor of the ship. On this bed-plate are two hydraulic cylinders, to which a double-ended ram is fitted, the central part of the ram being provided with teeth, which gear into the sector. Therefore, when the ship is in a state of rest the sliding in and out of the rams will cause the saloon to move on its own axis with a gentle but powerful motion. These movements, however, are controlled by a pair of delicately-balanced equilibrium valves. Hence it will be seen that when the ship is rolling at sea, this power of acting on the saloon enables the steersman to retain the saloon constantly in a perfectly vertical position, while the floor of the ship is rising and falling beneath it. The essential point of this arrangement is that the hydraulic apparatus has not to put the saloon in motion, but simply to prevent it acquiring any motion. Moreover, the *vis inertiæ* of a structure like the saloon, which will weigh some seventy or eighty tons, will greatly assist in resisting the initial tendency to motion."

The appellation of "steersman" given by Mr. Bessemer to the man who operates on the hydraulic valves, is not happily chosen, and has led some persons, to my knowledge, to imagine that the hydraulic apparatus is in some way connected with the steering of the ship. The man in question, however styled, stands, in Mr. Bessemer's working model, in a well, formed in the centre of the saloon, grasping a long horizontal lever which acts on the valves. In front of him is a spirit-level, suffi-

ciently delicate to indicate any tendency in the floor of the saloon, to which it is fixed, to depart from the horizontal position. Keeping his eye on the level, he instantanously checks any such tendency by giving a slight motion to the lever one way or the other, according to the indications of the level. In Mr. Bessemer's comparatively small working model the shifting of the weight of two heavy men from one side to the other would, if the saloon were devoid of controlling apparatus, certainly disturb its equilibrium, but I found that the man at the level had perfect control over that amount of disturbing cause.

Mr. Bessemer claims for this apparatus, and I believe justly, a quickness of action, smoothness, and facility of manipulation, combined with power, superior to any other agency now known. He has, moreover, long employed the same principle on a large scale for other purposes connected with the steel manufacture, and has, therefore, that confidence in its efficiency which experience alone can give.

Mr. Bessemer's ship is to be propelled by two distinct engines, outside the ends of the saloon, and each driving a pair of paddles, the centres of which will be 106 feet apart.

Two of the disturbing effects to which ships are liable, enumerated in the early part of my paper, may now be referred to, namely, No. 7, "Temporary vibrations caused by the concussion of waves," and No. 8, "Continuous tremor caused by the working of the engines." Mr. Bessemer's arrangement seems well calculated to reduce to a minimum these two effects, both of them distressing, the first to the timid, the second to the sick, whose sufferings are generally believed to be aggravated by the incessant trembling of a powerful steamer. The suspensory supports of the saloon will be furnished with thick beds of india-rubber, which will deaden tremor; and a space of 5 ft. all round between the saloon and the ship will prevent the wave shocks against her sides from being felt by the isolated passengers.

I must now once more advert to the motion of translation of ships. It is evident that none of the projects I have described have any direct tendency to diminish this motion in the slightest degree. The question is, what does this motion, separated from all others, amount to? We are singularly in the dark here. Every one speaks of the malign influence of the "up and down motion" of a ship at sea. In the discussion on a paper read by me on the 27th ult., at the Royal United Service Institution*, no clear apprehension of this motion seemed to exist even on the part of the scientific naval officers who spoke. This troublesome translatory motion seems doomed to be confounded with pitching; and whether or not it affects the bodily comfort of those exposed to it, it seems certainly to obfuscate the mental powers of most people who write and speak about it.

They are apt to forget that the up-and-down motion so much and justly complained of, is largely due to the angular pitching and rolling. For, to revert to the illustration of the beam of a fixed steam-engine, the piston-rod is seen to rise and fall vertically under the influence of the angular pitching, so to speak, of the beam, and yet there is no translatory motion here.

I have not met with any investigation of the amount of the translatory motions of ships, nor do I believe that any exact observations upon it have been made, the difficulty of eliminating all angular motion in a floating body standing probably in the way of such observations. But any one may notice that a small light floating body, such as a cork, will be raised and lowered vertically to the whole extent of the ripple on which it is borne, the motion of translation being exactly equal to the height of the ripple or wave, whereas a large ship in the same water will not be moved perceptibly. This clearly indicates that the extent of the motion in question depends on the relation of the height of the wave to the size, weight, and immersion of the body exposed to its action. In the case of a large ship, the fraction of the wave height through which she will be raised bodily will probably be very small. Mr. Merrifield, in the article I have before alluded to, estimates that, in the case of Mr. Bessemer's ship, the motion of translation may amount to 5 or 6 ft. He does not, however, give the date on which this estimate is founded. When it is remembered that in the Channel, ships are exposed more to chopping cross seas than to large regular waves, such as those met with in the open ocean, I am inclined to think the estimate an extreme one in the case of the Channel ships we are considering.

With reference to that, I may just mention

* On a proposal to mount heavy naval guns on the principle of the Bessemer saloon.

that the height of the great Atlantic waves was measured with great care, years ago, by Dr. Scoresby, and he gives their mean height to be—as well as I can remember, speaking from recollection—28 ft. That is a very extreme case in the ocean where waves attain their maximum height. Now, I doubt very much if Channel waves ever attain half that height. They always appear to be very much higher than they really are, but nothing is more deceptive. Its impetuosity rather tends to create the illusion of height, just as a fleet race-horse always looks larger in galloping than when standing still. Now, if Channel waves are never more than 14 ft. in height, I should very much doubt whether the larger ship would rise or fall 6 ft. However, that is mere conjecture.

It is only right I should mention, before leaving Mr. Bessemer's ship, that although in the first specimens to be built he only proposes to control the rolling motion, he expressly states that his invention can be extended to control the pitching also. I have seen his fully detailed drawings for this more complete arrangement, which, if carried into practice, would, by eliminating both angular motions, enable us to measure with some certainty the amount of the vexed and vexing rectilinear translatory motion.

It need hardly be said that both Captain Dicey and Mr. Bessemer seem fully alive to the necessity for providing the thorough ventilation, protection from weather, and commodious accommodation which their large ships are so well suited to afford.

It may here allude to another proposal for crossing the Channel, which was laid before the public in this room, under the auspices of the Institution of Naval Architects by the famous engineer, Mr. Scott Russell. Everybody who was present must remember the lucid and also very entertaining way in which he described his plan, which consisted in having large ships, without any peculiarity of form but such as would make them good sea-boats—large ships capable of having a train on board—so large that no existing harbor would have accommodated them. He proposed to create a harbor, or as he expressed it, make an island some distance off shore about a mile, I think. It was a circular island, with the centre scooped out, and an entrance to it, and this scooped-out portion of the island was to be large enough to receive his ships. There was to be a viaduct to connect the island harbor with the shore. His ships were to run into the circular harbor, land their passengers and goods on the edge of the island, and they were then to be conveyed by train to the Continent. That was, substantially, I think, his scheme, and no doubt it offered great advantages. But it is some time since it was promulgated here, and I have not heard anything of it since, and whether it is to be carried into effect, I know not.

It is difficult to institute a comparison between two arrangements differing so completely in principle as Capt. Dicey's and Mr. Bessemer's. And I think, perhaps, it will be best to leave their relative merits and demerits to be brought out by the discussion for which I have endeavored, as impartially as possible, to provide the material. I may, however, help to give useful direction to the discussion by naming some points in each of the new ships, regarding which differences of opinion have been publicly expressed.

In Capt. Dicey's ships, it is apprehended that the narrow passage in which the paddles work will permit free way to the water, and that high speed will therefore not be attainable. I have heard that experiments have been made on this point, and perhaps those who have made them may be present to tell us with what result. Another objection is that the Dicey ship has four instead of two wetted sides, and that the additional water friction thus generated will also retard her. I, however, expect to hear that this retardation will be overcome by additional engine power. A third objection, insisted on very forcibly by Mr. Reed, in the "Times," is that the connecting bridge will be subject to great and perhaps dangerous strains. No doubt the strains will be far greater and of a much worse kind than those of ordinary ships, and I must confess that I should not like to cross the Atlantic in her in a gale of wind until her character was well-established. But a contrivance must be judged by its avowed object, and the twin-ship is not intended for the Atlantic, but the Channel, where very high seas do not occur.

As to Mr. Bessemer's ship, the main objection deserving of notice is that, one pair of paddles being in the wash of the other, her speed will not be what is expected. It is, however, certain that her two engines and four paddles combined will give greater speed than one engine and two paddles of

the same power. The question is, how much gain will there be, or, in other words, is the gain economically obtained, or would a single engine of greater power give the same speed at a lower cost. It is also but fair to point out that only the occupants of the saloon will enjoy the whole benefit of Mr. Bessemer's suspension. I conclude that they will have to pay for the privilege, and that those in the unsuspended part of the ship will pay less. The question is, therefore, a commercial one, which experience alone can solve.

I will conclude by expressing my conviction that both ships will secure an amount of comfort in Channel-crossing hitherto undreamt of, and my hope that both inventors will reap the substantial and honorable reward of which their labors in so good a cause are fully deserving.

FURNACE GAS ENGINES.

From "The Engineer."

At a time like the present, when coal possesses an extraordinary value, every scheme for effecting economy in its use as a means of producing power deserves attention. We make no apology, therefore, for placing before our readers a suggestion, which, however crude, can be demonstrated to be sound in principle, and only needs, indeed, some considerable exercise of inventive talent to be reduced, as we believe, to successful practice. In many text-books will be found a comparison between the efficiency of heated air and steam as motive powers; but these comparisons, although always in favor of hot air, are usually put into a complex form, which renders them unintelligible to those who do not possess considerable mathematical knowledge. We propose here to show how hot air may be made to operate an engine in a way which eliminates many of the objections which have hitherto told fatally against the use of that fluid as a power-producing agent, and at the same time to utilize the suggestion as a means of putting in a very clear light the great economy which can be gained by the use of air instead of steam for the required purpose. We have already given one or two of the broad features of the scheme to which we allude, but we have not given any details to show the economy which might be secured by its adoption.

The paramount objection to the use of heated air lies in the fact that the cylinder, piston, and working parts generally, are burned out and destroyed by the high temperature of the heated air, its extreme dryness, and the impossibility of securing efficient lubrication. To overcome this difficulty it is essential that the air used should have a very moderate temperature, that is to say, it should not exceed 300 deg. Fahr. A second defect in hot air engines, and of hardly less importance, lies in the difficulty of heating the air. Dry gases take up heat very slowly from metal surfaces, and to obtain anything like a successful result the body of air passing over a hot surface must be much subdivided and broken up, and the surface should be very considerable in extent. Both these objections can be disposed of by admitting nothing but comparatively cold air to the working cylinder, and by heating the air which has to be heated, by direct contact with the burning fuel. In applying this principle in practice it is evident that we must go to work by a somewhat roundabout method. It is obvious that if we could establish a vacuum and maintain it, we could operate an engine with the ordinary pressure of the atmosphere, the exhaust from the cylinder being thrown into the vacuum. It is clear, therefore, that, granted the vacuum, it is possible to work an air engine with cold air. Again, if we think proper to augment the pressure, we may raise the temperature of the air supplied to the working cylinder in a closed vessel, the cold air being supplied to this vessel by a pump. It is a prominent feature of the scheme to which we now call attention, that the hot air is used almost exclusively to produce a partial vacuum into which the cylinder, working with cold or nearly cold air, shall discharge its contents at each stroke. To effect this object it will be necessary to provide a close vessel, which, for convenience, we may call the condenser. This we shall suppose to be full of cold air to begin with. It is then placed in communication with a lofty stack or a fan as the case may be, and the cold air is drawn out and replaced by the products of combustion from a suitable

furnace. All the openings are then closed, and the air cooled down. When it has cooled to its minimum temperature a partial vacuum will be left; into this the engine will discharge. When the vacuum has been sufficiently vitiated, hot air will be again introduced, and the cold air expelled or warmed up, and this process will be repeated in a way to satisfy the working conditions. We shall for the present enter into no details, but we believe it may be shown that the condensers, two or more of which will be required with each engine, may be of very moderate dimensions. Instead of going into particulars of the arrangements and mechanism required, we shall content ourselves with drawing a numerical comparison between such an engine and a steam engine working under nearly the same conditions.

A pound of ordinary coal, supplied with sufficient air for its complete combustion, will represent the discharge over the bridge of the furnace of 24 lbs. of gas, by far the larger proportion of which was previously atmospheric air. We may, indeed, without introducing an appreciable error, deal with the products of combustion as so much air. At the normal temperature of 60 deg. Fahr., 24 lbs. of air will occupy 320 cubic ft. Making certain allowances for loss of heat, we may safely assume that the gases will have a temperature of 1,500 deg. when delivered into the condenser, and at this temperature the volume will be increased to about 1,200 cubic ft. If we suppose, then, that the condenser holds 1,200 cubic ft., it can be filled with gas at a temperature of 1,500 deg. at atmospheric pressure, and weighing 24 lbs. By cooling this 24 lbs. of gas down to 60 deg., its volume will be reduced for the same pressure to 300 cubic ft.; or, the volume remaining unaltered, the pressure will be reduced to about one-fourth of that of the atmosphere, or say to a little under 4 lbs. As the engine exhausts into the condenser the vacuum will be vitiated, the available pressure on the piston descending from about 11 lbs. to nothing; but a little reflection will show that even under these conditions we can reckon on an available average pressure during the whole time the condenser is being refilled of $\frac{11}{2} = 5\frac{1}{2}$ lbs. per sq. in. It is possible, however, to maintain a much higher working pressure than this by means which will suggest themselves no doubt to our readers. Taking the case, however, as it stands, we find that each pound of coal will give us the equivalent of 900 cubic ft. of air at a pressure of $5\frac{1}{2}$ lbs. on the sq. in., even assuming that all the heat sent into the condenser is wasted. Now let us see what a pound of coal will do for us under the same conditions when actuating a steam engine.

We shall suppose, then, that a steam engine works at atmospheric pressure and without expansion. A pound of coal will in a fairly good boiler produce 240 cubic ft. of steam of atmospheric pressure. We may take the best vacuum which can be got in practice as representing an available pressure of 13 lbs. on the piston. The comparison then will lie between 900 cubic ft. at 5.5 lbs. pressure, and 240 cubic ft. at 13 lbs. pressure; and $900 \times 5.5 = 4{,}950$, while $240 \times 13 = 3{,}120$; so that the hot air engine will be more economical of fuel than the steam engine in the ratio of 4,950 to 3,120, or about as five to three. To render this calculation clear, let it be supposed that in the case of the hot air engine we have a piston moved through a distance of 900 ft. by a pressure of 5.5 lbs.; then the total work done will be 4,950 foot-pounds, whereas in the steam engine we have a piston moved through a space of 240 ft. with a pressure of 13 lbs., equal to 3,120 foot-pounds. It will be pointed out, of course, that the comparison should not be drawn between a steam engine of the most uneconomical type possible and the air engine. We shall therefore assume that by expansion the efficiency of the steam is augmented three times, a result which it is difficult to obtain in practice. The comparison will then stand between 9,360 and 4,950, from which it would appear that a first-class steam engine would be nearly twice as economical as a furnace gas engine.

But so far we have completely neglected the fact that the whole of the heat sent into the condenser with the air is supposed to be absolutely wasted, although it is evident that it can be made available just as the waste heat has been made available in Ericsson's caloric engine, by the use of a regenerator. If this heat is utilized to the last degree, the furnace gas engine will far exceed the steam engine in economy of fuel; but we will suppose, for example, that means are devised by which the hot air in cooling down heats the air to be used on the piston to, say, 300 deg. If we take the coefficient of the expansion of air at a

constant pressure, as 0.002 per deg. of Fahr., which is a little less than the true coefficient, we find that by heating the 900 cubic ft. of air to be worked through the engine, under the conditions we have stated, to 300 deg., we shall increase its volume to 1,440 cubic ft., and the efficiency of the air engine would then be represented by 7,920 foot-pounds, instead of by 4,950 foot-pounds; but this is not all. The 900 cubic ft. of air, at 300 deg., represents but 270,000 air units, while 300 cubic ft., multiplied by 1,500 = 450,000 air units. It is clear, therefore, that, after the air for the engine had been heated to 300 deg., a considerable margin would still remain for heating the air used in creating the vacuum. It is not necessary, we think, to extend the calculation, but it may be shown that, under proper arrangements, it would be possible to get as much work out of 1 lb. of coal, by means of a furnace gas engine, working with air in the cylinder of but 300 deg. temperature, as could be got out of 2 lbs. of coal in a first-class steam engine.

There are certain situations in which the space occupied by the condenser, etc., would be of no conceivable importance; but it must not be supposed that large condensers are essential to the scheme. The entire question of success or failure depends on the possibility or impossibility of cooling down hot air with great rapidity. If it is possible, for example, to cool down air at one-fourth of the rate at which steam is cooled down, then we should in the hot air engine have four condensers, instead of one as in the steam engine; and these condensers need not be very much larger than the cylinder. As a compensation, we should require no boilers, and the condensers would not occupy nearly so much space as the boilers would take up.

We have already stated that the suggestion embodied in what we have just written is crude, but we have said quite enough to demonstrate the possibility, in theory at least, of working an engine with furnace gases. That great economy would follow from the adoption of the principle is generally admitted, and several attempts have been made to apply the principle in practice, as, for example, by Cayley and Gordon. Such engines have always proved unsuccessful because they were worked by the hot gases direct, and the piston and cylinder were accordingly quickly cut to pieces. We have endeavored to sketch an arrangement which would render the use of furnace gas compatible with a low temperature in the cylinder. That there are great difficulties in the way of carrying the principle into practice no one knows better than we do; but the history of every successful invention is a record of triumph over difficulties.

CONSTRUCTION OF MODERN WAREHOUSES.

From "The Building News."

It cannot escape observation that the introduction of any new material into one branch of the constructive arts, invariably leads to its employment and adoption in others. Experience has also demonstrated the truth of the inverse of this statement, that is, that the failure and the subsequent abandonment of any particular material in one description of engineering or architectural work, is the prelude to the abolition of the use of it in numerous similar situations. Cast iron was extensively employed some years ago, not only as girders for railway bridges of large span, but also in the erection of factories, mills, and industrial workshops. It is not much more than thirty years since the old system of erecting buildings of the description under notice was abandoned, and the newer and more modern introduced. In effecting this change it must be admitted that the frequent occurrence of fires played a very important part. A mill or factory of ancient date, with its huge timber pillars, massive longitudinal and cross beams, heavy roof, and planked floors, was little better than so much tinder. The accidental lighting of a single lucifer, a mere spark, was sufficient to set the whole structure in a blaze. Another circumstance that tended considerably to favor the introduction of a more improved principle of construction was the increasing use made of machinery and mechanical means and appliances for accomplishing various processes and operations, previously performed by manual labor alone. The foundations of these old buildings were not suited to withstand the additional weight brought to bear

upon them. Any one who has travelled in the manufacturing districts cannot have failed to notice this fact. In those old factories in which iron columns and heavy machinery have been introduced, the walls are out of plumb, the windows and doorways distorted, and the angles and general lines of the building all out of square. Some months ago we visited an extensive warehouse and factory in Cheshire, in which the joists, from the increased weight brought upon them, deflected an inch and a quarter at the centre. It is impossible to avoid remarking that to load this floor with a crowd of human beings, as was constantly done during a pressure of work, was to place their lives on rather an insecure tenure.

The three principal points to be attended to in the construction of buildings of the character in question are, that they should be strong, durable, and fire-proof. Each of these qualities can only be insured by the exercise of much skill, patience, and discrimination in the selection of the different materials required. Above all, the necessity of a thoroughly reliable and secure foundation cannot be too forcibly borne in mind. Architects and engineers of late years have paid much greater attention to this point than formerly. Fortunately the universal employment of concrete, places at their disposal a material which if properly used never fails them.

It is not too much to assert that in future every warehouse, or other structure of a similarly extensive nature, will, except under very peculiar circumstances, be founded on concrete. In London alone there is an almost unlimited demand for the ingredients of which concrete is made. Gravel, blue lias lime, or more usually Portland cement, are used daily as concrete, in hundreds of tons, in and about the metropolis.

The manufacture of Portland cement received a stimulus about the time of the commencement of the Drainage and Embankment Works in London, which led to an enormous development in that particular business. Not only was the quantity made increased beyond all precedent, but the quality was greatly improved, in consequence of the Metropolitan Board of Works insisting that the cement should be capable of withstanding certain well-defined tests with respect to its tenacity and powers of setting. A solid mass of concrete, having a depth varying with the nature of the ground, but not less than 18 in., may be considered to be essential to the proper formation of the foundation of extensive warehouses or manufacturing premises. There is no difficulty in selecting the gravel—one of the ingredients of concrete. It should be clean, sharp, and dry, and not too small. Every practical builder knows good gravel at a glance, but it requires more than a glance to ascertain whether the other ingredient, Portland cement, is of a proper quality. It is in many instances the architect's or engineer's business to cause the cement to be properly tested, and to satisfy himself that it is up to the proper standard. The best guarantee to the builder and contractor of the genuine character of the cement is to purchase it from a good manufacturer. When a material is so universally used in the constructive arts as Portland cement, there are, as a matter of course, numerous spurious and adulterated imitations of it to be purchased cheaply in the market. Cement of a bad quality, however good it may appear to the eye, and however well it may set apparently, soon becomes no better than so much mud—a very unstable sort of a foundation for a large industrial establishment.

The foundations having been got in, the "carcass" of the building, as it is termed, can be proceeded with. This consists of the side walls and roof. The walls are either of stone or brick, and frequently of both, one material serving to give strength, the other ornament. A series of alternate walls and arches constituted the carcass of the older factories and mills, and scarcely any attempt at ornament was ever thought of. A very noticeable feature in the walls of the most recently built buildings of the kind is the introduction of wrought-iron plate and box girders.

A very good example may be seen at Stiff's pottery, in Lambeth, and most of the new shops erected in Ludgate-hill will be found to be designed in a very similar manner. The arches employed in former times are not applicable to the modern system. They take up too much headway, and, moreover, cannot afford the open and uninterrupted interval of space which is now indispensable. There is one advantage in employing iron girders in the walls of a building which is not always apparent. If the floor should be built, as frequently occurs, of arches, the final thrust is thrown upon the girders, and not upon walls.

Stone or brick, or both, cast and wrought iron, but preferably the latter, are therefore the materials constituting the carcass of the modern buildings we are considering. The windows, or, more appropriately speaking, the casements, are often constructed of cast-iron frames, into which glass panes are fixed, so that the use of timber thus far is confined to the doors, and even in some instances these latter are also made of iron. In any case, it can be readily understood that the materials mentioned are sufficient, exclusive of wood altogether, to build the exterior portions of factories and warehouses. As a a proof of the few materials which are absolutely necessary in the construction of large buildings, it may be observed that Milan cathedral is built entirely of marble and glass.

The design of the interior of a factory must depend upon the purposes to which the building is applied. As a rule, cast-iron columns or girders, with arches of brick, comprise the materials selected. In some modern examples, wrought iron has been substituted for cast, chiefly on account of its greater strength and lightness. It has been stated that wrought iron should be always used instead of cast, insomuch as the latter is liable to be melted by the action of fire. An accident of this nature is extremely improbable, and there is only one instance on record. It occurred at the works of Messrs. Sharp, Roberts, & Co., Manchester, in which some cast-iron columns melted and broke. But the circumstances were very peculiar and exceptional. A large quantity of fuel was heaped up round about the columns; this became inflamed, and generated a very intense heat, so that the columns were in nearly the same position as if they had been subjected designedly to a regular remelting. There is one point to be carefully attended to in supporting iron beams or girders upon the side walls of these buildings. The ends which bear upon the walls should be raised half-an-inch or a little more, to allow for the settlement of the walls. This slight settlement, which takes place in all walls newly built, is not necessarily due to any defect in the foundation. It is simply the result of its own superincumbent weight, and when once it has subsided, will not occur a second time.

There remains now to be considered the floors and the roofs of the buildings under notice. If the structure is to have any pretensions to being fire-proof, the floor must partake of that character. This can be easily accomplished by the use of brick arches and concrete filling-in of the spandrels. Instead of brick arches, wrought-iron plates bent to a curve are frequently used, being much lighter and not occupying so much headway. The objection respecting the employment of brick arches on account of their weight, can be obviated to some extent by using hollow bricks, as was done in the Saltaire Mills, near Bradford. There have been several "fire-proof floors" patented, which are so well known to our readers that it is needless to refer to them. It must, however, be admitted that in the construction of the floors, as well as of the roofs of these structures, timber is still very extensively employed. Moreover, the interior fittings of large buildings, which are not strictly manufactories, are usually of wood. The staircase should always be of either stone or iron. If the staircase of a building on fire be consumed, the only chance of egress for the inmates is the fire escape. As a means of communication with the different parts of a warehouse, speaking-tubes have superseded bells of every description, although those of the electrical character are occasionally adopted. Roofs are usually of timber when the building has any pretensions to architectural merit, but of wrought-iron trusses in other instances. A feature of great moment in this construction is that means are taken to insure thorough ventilation. Increased accommodation, more space, more light, more air, and more comfort, may be said to constitute the distinguishing feature of the modern structures to which we have drawn attention, in comparison with those of an older date.

There is one disadvantage under which we labor in the metropolis with regard to the æsthetical effect of our large mercantile and industrial establishments. It is that we have no cheap, good building-stone near at hand, and are in consequence obliged to use brick. We are not about to discuss the relative merits of the two materials, as it must be allowed that the employment of the former imparts an imposing and solid appearance to these buildings, which is peculiarly in accordance with their proportions and the purposes for which they are designed. A structure which supports on each story some thousands of tons of material is more fitly constructed of stone than brick.

A SOLUTION OF THE SEWAGE PROBLEM.

From the "Journal of Science."

The treatment of sewage has long been an important question of Sanitary Reform. But the discussion involves a second question, equally momentous,—that is its utilization, which is by no means implied in mere deodorization or disinfection. A forcible illustration of this is found in Lord Palmerston's celebrated definition—"Dirt is matter in the wrong place." The offensive elements contained in sewage are in the wrong place when sent in to the river, but are in their right place when they are separated from it, and reserved, like the farmer's manure heap, for restoration to the land at the proper time. We invite epidemics if we permit the former; and we must cease to expect a fair supply of corn, wine, and oil, or the other bounties of Nature, if we neglect the latter, while we continue to draw from the land all its nutritive properties. The value of land is daily increasing, and therefore the highest possible cultivation becomes necessary. The only means of increasing its productive powers is by manuring, and for this purpose *all* matters possessing real fertilizing value becomes a point of the first importance.

Many methods for dealing with the sewage of towns have been proposed. They may be classed under the four following schemes:—

1. Irrigation.
2. Filtration.
3. Destruction.
4. Precipitation.

These schemes may be considered individually or collectively in certain combinations.

Let us deal first with irrigation, and we may say at once that with us it has no favor, for it has been abundantly proved that at the best it is a disposal of sewage merely, and in no way its utilization; for the excessively rank vegetation of a sewage farm forced to take more than is good is no more an evidence of high farming than was Wackford Squeers an evidence of the high feeding of the Yorkshire school. But even as a *disposal* of sewage it falls lamentably short of efficiency, as may be seen by any impartial inquirer. Under the most favorable circumstances this system is inadeqate to deal with the entire sewage; for the quantity of land required annually to deodorize this (one acre for 100 people) is so large, in proportion to the land available for the purpose, that for financial, geological, and local reasons, the system could not succeed. There are other objections to irrigation with fluid sewage. Land for the purpose must be in propinquity to the town to which the system is applied, and this land may have to be bought in by the pressure of an Act of Parliament, at great expense, as it is generally opposed by wealthy landowners. Such opposition is to be expected; for the neighborhood of a sewage farm would certainly not be selected by the rich as a site for their mansions; and the value of land is consequently deteriorated.

The charge of miasmatic emanations arising from a system of sewage irrigation has been abundantly proved by evidence given before the House of Commons by eminent medical and sanitary experts:—

Mr. Thomas Hawkesley, C. E., says (in reference to the Blackburn Corporation Improvement Bill, March 15th, 1870): "Water irrigation carried on in warm weather is exceedingly unhealthy; in fact you make, so to speak, a kind of fen of the large area of land which you put the water over." . . . "Where the water is foul I can speak positively to it, from repeated observation in different places, that the odor, particularly at night, and particularly upon still damp evenings in autumn, is very sickly indeed, and that in all these cases a great deal of disease prevails; but I need not do more than upon that subject refer to the evidence taken by the General Board of Health itself." . . . "With regard to sewage irrigation this happens:—The sewage forms a deposit on the surface of the ground; that deposit forms a cake of organic matter; and that organic matter, when it is in a damp state, as it usually is, gives off in warm weather a most odious stench." Of the Barking farm Mr. Hawkesley says: "The stench was of a very fetid character indeed, and of very considerable intensity." At Edinburgh, at Carlisle, and at Harrogate, the state of the atmosphere varies with the state of the weather. Of Edinburgh the witness says: "I cannot call it a mere odor in the ordinary sense. Everybody who walks down to Leith from Edinburgh, or to Portobello,

in warm weather, cannot help being assaulted by it." At Carlisle, "they were utilizing only about one-sixth of the sewage." At Croydon, where the soil is the most favorable that could be had, consisting of only a slight covering of alluvial matter upon chalk, gravel, and gravel-flints, "the people complain of this fetid smell in summer, and particularly at night, and of a very low state of health in consequence;" and "the water does not run off clear," "nor nearly free from organic matter." At Birmingham "it has a very prejudicial influence on the value of property." "Irrigation works with sewage water for the utilization of sewage are most pernicious." Mr. W. E. Cressy, M. R. C. S., states, to the same Committee, that in the case of the sewage farm belonging to the Croydon Board of Works there has been, since 1867, typhoid fever in every cottage on the estate, which he refers to the existence of the farm. The water from the wells in the neighborhood becomes putrid if allowed to stand for 24 hours. Cows feeding on the grass from this land yield milk which has been proved, by a series of experiments, to cause fever.

Dr. Henry Letheby, Medical Officer of Health to the City of London, gave evidence before the House of Commons in reference to both the Blackburn and Reading Bills, on the 15th and 25th of March, 1870. He states that, taking the condition of the sewage put upon the land at Croydon, Norwood, Beddington, Rugby, Carlisle, and Worthing, the average proportion of matter in solution in the sewage before it was put upon the land, was 32.77 grains. As it ran from the land it contained 34.3 grains, there being an increase in the solid matter after flowing through the land. The necescary conditions for irrigation, which he admits are not always present, are porous soil and good subsoil drainage. Frozen soil will not allow the sewage to sink, and a heavy rainfall will prevent it; and Dr. Letheby's experience has shown him that the land acts upon the sewage only at the time of active vegetation, "but that during the time of the dormant state of the vegetation the sewage runs off that land pretty nearly as it goes on it." He shows that, besides the acre of land for every 100 people, there must be another acre in reserve when that cannot be doing its work. The chief objections he considers to be, in the first place, the saturation of the soil with excrementitious matter, which is constantly giving off—sometimes to a great extent, at other times not so much—effluvia capable of producing disease. Secondly, "the subsoil water is always charged with decomposing matters, the residue of the sewage; and we know from the investigations recently of Dr. Pettinkoffer, who has examined into the question in England and Germany, and almost all over the world, that there is no more fruitful source of disease than a subsoil water charged with offensive matters, and altering in its level. The soil becomes filled with offensive gases, and he traces cholera and typhoid fever to these emanations, and he attributes epidemics to these emanations. Again, we have subsoil water which runs into the neighboring wells, and whenever there is subsoil irrigation the neighboring wells are offensive." . . . "There is another objection, which I look upon as the most serious of all: parasitic diseases in the human body are always derived from parasitic diseases in the flesh of the animals we eat. I hold in my hand a report from the most experienced man in this subject—I may say in the world—Dr. Cobbold. It treats of the more than probable, the certain introduction of serious parasitic disease among the community, if sewage be put upon land as a means of utilizing it."

These are the objections to the utility of the process of irrigation merely as a means of *disposal* of the sewage,—and they are very great,—whilst as we before observed, as to the equally important question of utilization, its claims are very small indeed.

The abundance of crops produced on a given area has been quoted in favor of the system of irrigation. The finest manurial substances are possessed by the constituents of sewage; but the irrigationist is so wasteful in their application, that, in a majority of cases, there ensues not a healthy crop, but a mass of overgrown, rank grass material, of no more nutritive value than weeds; for be it distinctly remembered that this is not a question of manuring with sewage when necessary,—but the compulsory application of enormous quantities, in season and out of season, till the surfeited land is sick, and even then it has to take more still. If this waste were prevented, by the conversion of the sewage into a dry, portable, inoffensive manure, then this manure might be stored until it could be employed at the proper season without injurious effect; but to dose vegetation with

equal quantities of manure, day by day throughout the year, is an absurdity which of itself is sufficient to condemn sewage irrigation.

The second process, that of filtration, appears to be involved in some obscurity,—that is to say, there are attached to the term several meanings, of greater or less comprehension. Not a little of the confusion appears due to the Rivers' Pollution Commission having discussed "intermittent downward filtration," without defining the term. We are told that irrigation owes no inconsiderable amount of its success to the contemporaneous effect of filtration of sewage through the soil, and, confusion worse confounded, we are instructed that "irrigation involves filtration." We, however, will take filtration to mean the passing of the sewage water through an artificially-constructed bed of sand, charcoal, etc. Filtration by itself is simply a method of disposing of sewage, not of utilizing it, and therefore we hold it in no more favor than the other; for we maintain that unless the manurial elements are preserved *for* the land, as well as *from* the river, the problem is but half solved. Filtration processes do not profess to do the former, and as for the latter, wo do not find that they are very successful, so far as efficiency is combined with economy.

Let us revert, for an instant only, to the filtration—intermittent, or downward, or irrigation-filtration, or otherwise—of the Rivers' Commission. We will first describe the construction of such a filtering-bed, and will then take in consideration of the efficacy of this quasi-filtration the evidence of Dr. Frankland. The illustration is the construction of the Merthyr Tydvil beds, described by Mr. T. C. Scott, a strenuous advocate. "The filtering medium consists of 20 acres of land, drained 6 ft. deep, and divided into four areas of 5 acres each. Each of these receives daily, for six hours out of the twenty-four, the sewage of 20,000 persons, represented by 900,000 gallons, or at the rate of 73,000 tons per acre per annum. To utilize advantageously, according to our present knowledge, the quantity of sewage thus dealt with, 200 acres of land are required, being at the rate of 1 acre for every 100 persons, or for 7,300 tons of this sewage." Now for the opinion of Dr. Frankland, who is an advocate of the irrigation system, and a Rivers' Pollution Commissioner; "I think it (this downward filtration) is an important part of our knowledge; but although I have had so much to do with it, I confess I am not very sanguine of its success as applied to large volumes of sewage, and for this reason: you collect upon the surface of your filters a large quantity of suspended matter from the sewage, which is fecal matter in a state of decomposition, and we should be afraid that this matter so collected would be offensive to the neighborhood. No plant can live upon the filter which is deluged in this way with sewage. This cannot be carried out along with plant growth, and consequently you have not the removal of those noxious constituents which accumulate on the surface by plant life, such as you have in irrigation." Thus, the filtration of unprepared sewage leaves us with far higher chances of miasma than do the evils of irrigation.

The process known as Weare's is a true filtration process, and is on a small scale said to be satisfactory. It has been employed in the workhouse at Stoke-upon-Trent; the filtration being effected through vegetable charcoal and fine ash, altogether a different method to the irrigation-filtration system. The filtering medium is placed in tanks through which the sewage percolates. The effluent water, however, still contains in solution a large proportion of putrescible organic matter, and is below the standard required by the Rivers' Pollution Commissioners, or by the Conservancy of the Thames.

But the evidence brought before the Parliamentary Committee on the Birmingham Sewerage Bill, in April and May last, has, we think, given the death-blow to sewage filtration. After fourteen days' hearing of the evidence of the leading authorities in Chemistry, Engineering, and Agriculture, the Select Committee attached to their approval of the Bill the condition that "*No sewage be put upon any land without having been previously defecated in tanks.*"

The third scheme of getting rid of sewage, viz., that of destruction, requires only a brief notice. By its very nature it forces us to condemn it: destruction has always been a favorite method of disposal of inconvenient elements, from time immemorial. Considerable difference of opinion exists as to what constitutes inconvenient elements,—but once admit the principle, and we find men using it to justify the murder of children by Lycurgus, and the monster fires of religious persecution. For our own part

nothing will satisfy us but rational utilization. Under the head of destructive processes we include the lime process of Tottenham and General Scott's cement process. By General Scott's process an effluent of a low standard of purity is obtained, whilst the result is in an agricultural point of view the most wasteful that could be devised. The sludge instead of being returned to the land is employed in the making of a kind of Portland cement. Human beings live directly and indirectly upon the produce of the land. Now scientific agriculture tells us that land unless properly manured becomes soon exhausted, and it is clear that the waste products of human beings, being most valuable in rendering the land fertile, should be returned to the land as manure, and not be destroyed. Few persons have any idea of the enormous waste which is committed in casting London sewage into the Thames. Mr. Mechi, a great authority on all agricultural subjects, tells us that the inhabitants of London consume *daily* the annual available produce of 20,000 acres, and a similar quantity is required weekly for London horses. The manurial wealth of this 20,000 acres of land is absolutely wasted, and the country thereby loses as much food as if three million quartern loaves were daily floating down the Thames toward the sea.

We come now to the consideration of the fourth scheme of defecating sewage, by precipitating the solid constituents. The object of precipitation is to remove in a solid, dry, or semi-dry state the putrescible constituents of the sewage, and to render the filtrate or effluent water sufficiently pure to mingle with our streams, or be employed for purposes of irrigation. There are several processes which profess to remove more or less of the impurities from the water. Amongst these may be mentioned the Phosphate Sewage Company's process, the lime precipitation process, and the A B C process. In the Phosphate Sewage Company's process "the water is left still maintaining all its nitrogenous and valuable properties, *plus* any excess of phosphoric acid which has been added, and, therefore, highly useful for the irrigation of cereals and other crops." This process, which was invented by David Forbes, F. R. S., when compared with those with which we have been dealing, appears a very admirable one. It is, however, from a technological point of view, somewhat deficient in economy. For the ingredient added to the sewage is expensive, too expensive with regard to the return in practical good obtained from its use in agriculture; and unfortunately those plants which require most phosphoric acid bear irrigation least. In a theoretical point of view, if we overlook the infringement of the rule of economy, the process is attended with a high degree of consistency. By no means is the preceding statement true of all precipitation processes. The lime process, as an instance, produces a precipitate containing a large proportion of lime, possessing but feeble or no manurial power, and readily putrefying; while the effluent water, instead of being pure or even suited to the purposes of irrigation, contains introduced foreign matter inimical to the land and the life of plants.

The process of precipitating by sulphate of alumina the valuable constituents of sewage, and utilizing at the same time the purifying power of charcoal and clay, is that to which we decidedly give the preference, as by this means the water is practically purified fit to be discharged into a running stream, and the deposit is retained in a form entirely inoffensive and capable of being turned into a dry and portable manure. This process has been before the world for some years as the A B C process, worked by a company called the Native Guano Company, and the claims it set up three years ago to have solved the great social problem we may now pronounce to be fully justified by facts; its principles were correct, the mechanical arrangements for conducting them being alone defective. The name of the process has been derived from the initial letters of the principal constituents of the precipitant: Alum, Blood, Clay, and Charcoal. We will consider the action of these substances upon sewage, taking them in order.

The alum was for a considerable time a source of expense, it being added to the sewage in the form of ammonia-alum. Ammonia-alum has the further disadvantage that the ammonia remains in the effluent water. A much more economical, and as effective a substitute has been found in a crude sulphate of alumina manufactured at $\frac{1}{4}$th the cost.

The action of the sulphate of alumina may be briefly described.

In contact with sewage—a slightly alkaline liquid charged with nitrogenous or-

ganic matter—the alumina is separated in flocks, and, by virtue of its remarkable affinity for dissolved organic matter, each particle seizes hold of, and drags down with it, a corresponding particle of nitrogenous impurity. The blood here comes into play; this is essentially a liquid highly charged with albumen; albumen is instantly coagulated in the presence of alum, and in the same way as this ready coagulability of albumen is utilized in fining wine and coffee, so it is made use of in this process by joining with the alumina in its precipitation, uniting it in a net-work of fibres, and giving it, as it were, arms wherewith to seize upon and drag out of solution still more putrescible constituents.

But the precipitated hydrate of alumina is light in character, and although it would ultimately settle, leaving a clear liquid above it, the slightest agitation causes it to float up, and thus renders it difficult, on the large scale, to drain off the mud. At Paris sulphate of alumina has lately been employed for clarifying several hundred thousand gallons of sewage; and among the many defects of this process, that of imperfect settlement was by no means the least. Here the action of the clay is apparent. This substance has a curious physical property; when finely ground up with water it forms a creamy emulsion, which takes many days to settle; many rivers, in time of flood, owe their turbidity to this cause: the Seine at the present time is a striking example, its water being in color, although not in actual impurity, as bad as the Thames below London Bridge. But when this creamy liquid meets with sulphate of alumina, the clay coagulates like albumen, and settles down in heavy granular flakes. Now in the A B C process these three precipitations—that of the alumina, that of the albumen, and that of the clay—take place simultaneously, and in each other's presence; they become closely locked together in a triple alliance; the heavy character of the clay particles gives density to the mass, and causes it to settle rapidly, and remain in a compact form at the bottom of the tank.

Were the object merely to produce an easily dried precipitate and a clear effluent, nothing more would be required; for not only has this precipitate carried down all the suspended matter, but much of the dissolved nitrogenous and albumenoid impurities have fixed themselves on to the alumina, whilst the clay has also performed its part in absorbing and carrying down a good proportion of the ammonia. But there still remains the probability, if not the certainty, of foul gases being present, whilst the water, though clear, may nevertheless be colored. These residual impurities are attacked by the charcoal: the powerful affinity of animal charcoal for organic coloring matter corrects the one evil, whilst the well-known absorptive action exerted by vegetable charcoal on the gaseous products of putrefaction corrects the other. In the way of purification little more remains to be done.

These reactions, by a modification in the order in which the purifying ingredients are added, are effected at once, with a certainty of uniform results, and, by a simple mechanical arrangement, variation in the dose of each constituent required by a variation in the strength of the sewage can be readily controlled.

The method of applying the ingredients is extremely simple. The clay and charcoal are incorporated in a grinding mill with the aid of sufficient water to form a thin paste. This paste flows into a tank, and is constantly agitated until it is required to be mixed with the sewage. By the side of the mixing-room is a smaller room, through which passes a channel or trough. At one end of this channel there rushes in the London sewage, and with it an unmistakable odor. The B C mixture, or thin water-paste of clay and charcoal, is admitted to the trough by a pipe from the store-tank; the sewage in its passage past this pipe carries with it the mixture, and the two after well mixing proceed on their way past a second pipe connected with a tank containing a supply of sulphate of alumina dissolved in water. All that is now requisite is to allow the sewage, B C mixture, and alum to flow in inodorous company to the settling tanks. The channel leading to the tanks has its course interrupted by numerous ledges, which serve to cause the more perfect intermixture of the sewage and the disinfectants. The first tank in which the sludge is allowed to settle contains the principal portion of the precipitate. The clear water is allowed to flow off continuously from the first tank into a second tank; and the remainder of the mud is deposited in this and in the other tanks into which it flows. From the last tank the water is conducted to the river, appearing as a clear, inodorous, and tasteless effluent. When sufficient sludge

has been collected in the first tank, the treated sewage is shut off from this, and permitted to flow into another tank, which then forms the first of the series. As much of the water as possible is then run off from the mud, and the latter is drawn into the acidifying tanks, where a small quantity of sulphuric acid is added to prevent the loss of any ammonia. From the acidifying tanks the semi-dry mud is pumped into the drying-presses, whence it issues in a cake. This semi-solid mud is then further dried by a most ingenious application of heat in revolving iron cylinders. The wet mud is passed in at one end, and dry manure, in the form of an inodorous and inoffensive powder, falls from the other end, at the rate of 5 tons in ten hours, at an expenditure of a few cwts. of coal.

If space enough be available the mud may be simply pumped from the bottom of the settling tanks into large open-air stanks, where it dries under the influence of the sun and air. Not the slightest offensive odor is apparent during any stage of this drying.

The dry mud in powder, and forming excellent manure, is removed from the sheds, and packed into bags for transport.

We have thus traced the process from the sewage to the manure and the effluent water. Before entering upon any statements with regard to the value of the results, we will more fully detail the process as it is followed at the experimental works at Crossness.

Crossness is situated on a projecting part of the southern shore of the Thames, between the Plumstead and Erith marshes, and is the southern outfall of the London drainage. The quantity of sewage now daily discharging at Crossness is 50,000,000 gallons. Large as this quantity may appear the enormous engines employed in pumping the sewage are fully equal to the task, for they are capable of lifting 280 tons in a minute, or nearly double the average flow. The transformation of such a mighty mass of filth into heaps of shining gold is a feat worthy of the days of the alchemist, or rather of the days of modern chemistry. Of this quantity of sewage the works of the Native Guano Company are capable of dealing in the twenty-four hours with 500,000 gallons, drawn from the cross-cut, or culvert through which the sewage runs into the principal reservoir. This quantity amounts to 1 per cent. of the whole delivery. Thither the sewage flows into the sump of a pump worked by a 15 horse-power steam engine, whence it flows into contact with the A B C constituents as we have described.

From the mixing trough the sewage, as described, flows to the settling tanks. These tanks are six in number, and are constructed of concrete, each being 50 ft. long by 20 ft. wide and 8 ft. in depth. When leaving the last settling tank the effluent water is caused to take a considerable fall, so as to afford room for the construction of a subway in such a manner as to place the sheet of water—as clear as plate-glass—between the visitor and the diffused light of the sky. In this position the transparency of the water is subjected to a most severe test, leaving no doubt as to the previous subsidence of all solid particles. The effluent water is run off to the Thames in a shallow brick-built conduit, about 4 ft. wide by 270 ft. in length, and arranged during its course to form several miniature cascades.

During an official trial, lately completed, extending over eighty days, there were used 80 tons of dry A B C materials, whilst the "native guano" obtained amounted, in the dry state, to 131 tons, showing an increase of more than 63 per cent. The amount of sewage treated during this time was 11,672,000 gallons. Therefore 1 ton of dry native guano was obtained from 89,100 gallons of the Crossness sewage.

The Crossness works are calculated to have cost the Company considerably more than it would be necessary to expend upon any works dealing with much larger quantities of sewage; but it is estimated that £5,000 would amply remunerate the contractors for works which should deal with the sewege of 20,000 inhabitants, and that £1,000 additional capital would provide for the working expenses. This, however, is not a matter with which we have to deal in detail.

The state of the effluent water may be viewed from two points—that of an analytical chemist, and that of a practical man of the world. The former can, without difficulty, make out a case which would lead persons ignorant of the weakness of purely chemical reasoning to condemn any water in the world; and a sensation is readily created by manipulating figures in such a way as to convert *grains* of the normal constituents of a good drinking water into *tons* of impurities, and by classifying perfectly

innocuous substances under the fearful title of "previous sewage contamination."

Common sense leads one to judge of a water by other standards than those of theoretical chemistry. The effluent water from sewage purified by the A B C process, falling into the Thames at Crossness, into the Aire at Leeds, into the Croal at Bolton, and into the Seine at Paris, may not at all times come up to the fanciful requirements of a scientific chemist,—although the inhabitants of many towns and villages habitually use and thrive upon a worse water; but no intelligent man of the world will doubt its suitability for admixture with ordinary river water. It is perfectly limpid and colorless; it has no smell, and so little taste that were it not that the tasters know whence it comes they would not notice it. On standing, the water acquires no disagreeable odor; it forms no deposit, nor does it give rise to "sewage fungus" or other vegetable growth along the watercourses. Fish will live in it, not only hardy varieties, but the more delicate kinds, such as gudgeon, to which a very slight taint of impurity is fatal. When the inquirer further finds that the effluent water is not too hard to interfere with its domestic use for washing or cooking purposes, he will endorse the opinion which the writer has deliberately formed, that there are not many English rivers on which large towns are situated which are as free from real impurity as the effluent water from sewage purified by this process.

Instead of fixing upon a fanciful standard of purity which could never be attained in practice, common sense decides that an effluent water from sewage is fit to be discharged into a running stream if it contain a less percentage of impurity than the water of that stream; the word "impurity" being not strained beyond its legitimate meaning, or made to include perfectly harmless constituents.

Let us now pass to the next point of inquiry—the manurial value of the "native guano," and the cost at which it is produced.

Of the value of a manure, chemistry can tell us little more than it can of the value of water. Just as mere chemical analysis would utterly condemn water containing Liebig's extract, infusion of tea, or a glass of bitter ale, as largely contaminated with nitrogenous organic matter or albumenoid ammonia; so chemistry, by taking a fictitious standard for manures, and judging only by the percentage of two of the many necessary constituents of the food of plants, gives an arbitrary money value to a manure, which is often exceeded by the price it fetches in the market. Agriculturists frequently pay more for nitrogenous and phosphatic manures than the price assigned to them by chemical analysis, and the sales of "native guano" form no exception to this rule.

In the autumn of last year the writer satisfied himself as to the alleged agricultural value of the manure, by personal inquiry amongst the farmers who had used it. With scarcely an exception, the farmers (of whom he saw 20 or 30) were unanimous in their approval of "native guano:" many of them were shrewd, intelligent men, well acquainted with the various artificial manures in the market; they had tried "native guano" with intelligence on different fields against other manures, and were assured that, putting equal values per acre, it was superior to most manures in the market. Moreover, an examination of the books of the Company shows that the good opinion of agriculturists was genuine, inasmuch as a man who, the first year, would grudgingly take 1 ton as an experiment, the next year took 10 tons, and the third year would increase his order to 20, 50, and even 100 tons, grumbling that the limited supply prevented him having all he wanted.

But it must not be imagined that the results of the laboratory and of practice are altogether anomalous in the case of the native guano manure; there is simply a difference in degree, and this difference arises from the non-existence of a fixed chemical standard of manurial worth. Nor does chemical analysis always show a low money value for "native guano." Samples submitted, at the Paris works, to one of the first analytical chemists in France (M. Terreil, Aide-Naturaliste en Chef des Travaux Chimiques au Muséum d'Histoire Naturelle) are reported to him to be worth in their dry state 108.6 francs per ton, or, when reduced by the normal amount of moisture present in "native guano," and converted into English money, £3 12s. 5d. per ton, whilst the cost of production is far below that figure.

As more particular evidence of the manurial worth of the guano, we may refer to the results obtained on the experimental

farm of 7 acres established in connection with the works at Crossness. The farm, as is indeed the entire system, has lately been under the supervision of the Metropolitan Board of Works. The following are the returns from 9 yards square:

Golden Drop Wheat.

	lbs.	ozs.
Native guano, 15 cwts per acre.....	6	4½
" " 10 " "	6	1½
No guano...	2	14

White Rough Chaff Wheat.

	lbs.	ozs.
Native guano, 15 cwts. per acre.....	6	7
" " 10 " "	5	7
No guano.....	5	4

Revet Wheat.

	lbs.	ozs.
Native guano, 15 cwts. per acre.....	11	0
" " 10 " " 10		14
No guano.....	6	8

Black Tartarian Oats.

	lbs	ozs.
Native guano, 15 cwts. per acre.....	6	8
No guano.....	3	14

These results are worthy the attention of the farmer; but they are in no way surprising, for it is universally admitted that town sewage has manurial value; and as the ingredients of the A B C process which are added to the sewage have no *destructive* effect upon the constituents of the sewage, it would be a matter of much greater surprise if the "native guano" were found to be without manurial value. Further evidence in favor of the manure is, that there is a demand for it at the rate of £3 10s. the ton. That at Crossness the manure has cost more than this sum to produce is extremely probable, for the machinery, steam-engine, and tanks have been apparently arranged with the object of getting the minimum of work at the maximum of expense. Probably some of this is due to the necessity of erecting works before the most advantageous method of carrying on the process had been ascertained, whilst some of the apparent waste of money may be rendered necessary by the show character of the works, and the necessity of having everything aboveground to answer the accusation of improper dilution of the effluent. But when it is considered that fifteen times as much coal is being burnt there* as was sufficient for the same work at Paris; that the alum is costing three or four times as much as it need; that an experienced chemical superintendent is included among the staff; that the rest of the staff is about twice as numerous as need be; and last, though not least, that for the greater part of the three months' official trial, the sewage which has been treated has been excessively dilute, owing to heavy rains;—when all these extenuating circumstances are considered, the wonder is, not that the "native guano" produced at Crossness has exceeded £3 10s. per ton, but that the price has not risen to twice that figure. Let us turn to other works conducted on some approach to economical principles, and a very different result will be seen.

* This does not include coal used for artificially drying the "native guano" at Crossness.

At Paris the expenses are higher than need be, owing to their being show works, and necessarily conducted with some disregard to economy. The works being simply for experimental illustration, were carried on intermittently, and were seldom in full operation, except when visitors were expected. The usual take of sewage was at the rate of 4,800 gallons per hour, but on some occasions the working was pushed until the sewage was flowing at the rate of 10,000 gallons per hour. At this rate the precipitation and the settlement proceeded without difficulty, whilst the effluent continued to flow away without deterioration. Let us take the data of these works as the basis upon which to draw up a profit and loss account of a day's work.

Ten thousand gallons of sewage per hour amount to 100,000 gallons per day of 10 hours.

For this are required the following chemicals:—

	Kilos.		Kilos.	Frs.
Animal charcoal...	250 at 170 frs.		1,000	= 42.5
Vegetable charcoal.....	500 at 50 "	"		= 25.0
Clay.....	600 at 6 "	"		= 3.6
Lime and blood.....	70 at 12 "	"		= 0.8
Sulphate of alumina.....	162 at 130 "	"		= 21.0
Total used.....1,582.....			.....costing	92.9

The labor consisted of—

Four men, wages per day.....	13.75 Frs.
One superintendent.....	10.00 "
Add one extra man.....	4.00 "
	27.75 "

The steam-engine burnt less than half a ton of coals a week. This, with a few sundries, such as oil, etc., amounted to about 36 frs. per week.

The mud was simply pumped from the bottom of the tank into an open-air stank, where it rapidly dried under the influence

of the sun and wind, assisted by the porosity of the soil. The drying therefore cost nothing.

Owing to the excessive dilution of the Paris sewage from rainfall, from the copious street washings, and from the fact that most of the night-soil is carted away to La Villette, the yield of dry "native guano" was very poor, not more than 114 parts being obtained for every 100 parts of A B C materials added, as against 163 yielded under similar circumstances from London sewage. As 1,582 kilos. of A B C materials were added, the "native guano" would be 1,808 kilos.

The total expenses were—

Chemicals	92.90 frs.
Labor	27.75 "
Coal and sundries	6.00 "
	126 65 "

As 1,808 kilos. cost 126.65 frs., therefore 1,000 kilos would cost 70 frs., equal to £2 16s. per ton.

The value assigned to this manure was, as already stated, £3 12s. 5d. per ton.

Had the price been taken at which the clay alum can be made in England, viz., £2 per ton, instead of the French price, the expenses would have been still less per ton.

The writer has been allowed an opportunity of going through the accounts of the Hastings Works for the last six months. The cost of the "native guano" produced here averages £2 4s. 1d. per ton. The operations are not carried on as economically as they might be, and there are several serious items of current expense which would be avoided in subsequent works.

At Bolton, according to the certificate of the Mayor of the Corporation, who are themselves working the A B C process under a royalty, the manure is produced at a cost of £2 6s. per ton. The royalty derived by the Native Guano Company from the profits of the Corporation of Bolton amounts to 1 per cent. of the entire capital invested by the Company; so that it requires but a few more applications to realize the permanent payment of a satisfactory dividend.

We are now in a position to make deductions from the evidence given before the House of Commons with regard to the value of the process.

Mr. Hawksley says:—"Now, the great virtue of this new method (A B C) is this, that while it is just as available as the old process of precipitation hy lime, it produces a manure which can be sold to a profit, and the whole thing can be done in a moderate compass; and having been done in a moderate compass, of course it does not render it necessary to acquire a gentleman's estate by compulsion, or to produce these marshes which are injurious to the health of the neighborhood. . . . The manure is now become of great value. . . . By this new process a valuable manure is produced, which sells at £3 10s. per ton, whereas the other manure (lime process) will only sell at from 1s. to 2s. 6d. per ton."

Dr. Henry Letheby says:—"The process is carried out at Leamington so satisfactorily that the effluent water is practically disinfected."

Dr. Frankland admits that he believes "the previous application of some chemical process, such as "Sillar's (A B C) process, would entirely obviate that difficulty (the clogging of the filter) attending downward filtration."

There is one important property of the prepared "native guano" which we have still to notice. During the progress of the experiments at Leeds it was discovered that the "native guano," when made into a powder and mixed with night soil, absorbed all the moisture, thoroughly deodorized it, and rendered it a dry, inoffensive, and inodorous manure, capable of being easily transported without inconvenience. So valuable was this manure found to be that it was easily disposed of at £4 per ton, in quantities of 40 tons at a time.

From this discovery it followed that the A B C mixture should be employed to precipitate the coloring matters from refuse dye-waters of large dye-works. Some experiments were instituted in the laboratory, and the results were so satisfactory that the adoption of the process would fully answer the requirements of Mr. Stansfeld's bill for preventing the pollution of rivers.

The writer has thus endeavord to give an outline of the A B C process of utilizing sewage, to state, and to answer, objections to the process. The chief objections may be summarized as follows:—That the "native guano" is of no manurial value; this statement is untrue in fact. The writer has considered this objection very fully in a letter published some months since, a portion of which may be quoted here. "When manurial value is mentioned, a distinction must be made between the value assigned by chemical analysis and by actual experi-

ment on a farm. The former method of valuation is most erroneous, as it only takes into account two constituents, and omits others of equal necessity to the plant life. Chemical analysis would assign scarcely any or no value to such substances as sulphate of lime, soot, the warp of the Humber, and the mud of the Nile; whilst, when a chemist does assign a value in money to a guano or a superphosphate, the price he fixes has little or no relation to the actual selling price. Farmers judge of its value by actual trial on their fields. It is in this way they fix the price it is worth their while to pay for the superphosphate, and in the same manner they judge of the value of 'native guano.' My observations at Leamington and the neighborhood proved satisfactorily to my mind that the 'native guano' made there had a very high manurial value, and the farmers to whom I spoke about it had tested it in too many ways, and were too shrewd judges of such matters to be deceived in ascribing to native guano what was really due to previous manuring." The second objection is that the cost of the manure is more than £3 10s. per ton. In some experimental cases, perhaps, the cost has exceeded this amount per ton; but in cases where actual work has been commenced, this amount has never been reached.

But let us for a moment suppose that no profit at all resulted from the sale of the manure; and that the sewage of London, we will say, had to be dealt with at the price of £2 per 100,000 gallons (and on the large scale it could certainly be treated at less than half this cost). We have then the sewage of London, amounting to 100,000,000 gallons per diem, treated (supposing the population to be 3,265,000) at 4s. per head per annum. The annual ratable property in the metropolis amounts, according to the Valuation Act of 1869, to £19,971,000. The cost of dealing with the whole of the London sewage could therefore be defrayed by a rate of 7-8ths of a penny in the pound. These facts are in themselves a sufficient recommendation of the process.

That the process should encounter opposition is not only possible but very probable. Its adoption will affect many vested interests, as well as the interests of rival schemes. But ratepayers, whether they be scientific men or not, would do well to investigate for themselves the claims of the A B C process. And not only the ratepayer, but every man who has a voice in the welfare of the nation and its production of food, or who desires that our towns should be healthy, should judge for himself of the value of the process. It may then be repeated that the claims of the A B C process to public confidence are threefold:—

I. It deodorizes and disinfects sewage, and precipitates the suspended and much of the injurious dissolved matter without giving rise to any nuisance; it converts the deposit into a dry, portable, and inoffensive powder, possessing considerable manurial value.

II. It leaves the effluent water in a state of practical purity, fit to be discharged into any river.

III. It effects these important sanitary requirements at a cost, which not only relieves the ratepayers of expense, but even yields a profit, owing to the ready sale of the "native guano" at £3 10s. per ton, and its production at a cost of not more, and probably much less, than £2 a ton.

THE USE AND ABUSE OF DYNAMICAL TERMS.

From "The Engineer."

We have long felt convinced that the greatest impediment met by one who wishes to acquire sound views on theoretical mechanics consists in the uncertainty as to the meanings of the words expressing the fundamental ideas of the science. This is more especially the case with that branch of mechanical science known as dynamics, or, more properly speaking, the science of motion, and not the science of forces, as its Greek derivative would imply. We so often have inquiries—in fact, inquiries that we could almost stereotype—on these subjects, from Whitworth candidates and others, that we have determined to carry out the unusual course of almost reprinting several articles we published a number of years ago on the subject. Provedly useful to students now of considerable standing, deserving and requiring attentive reading, they are inaccessible to many to whom we should otherwise refer them, as the num-

bers containing these papers have been long out of print.

It is notorious that the same dynamical terms are used by different writers with different meanings, and that exactly the same notion is expressed in quite different terms. Nor is the unhappy reader the only puzzled one. It is often very evident that the writer himself not seldom gets entangled in his own loose definitions and language. A remarkable exception to this common rule was formed by the late Professor Macquorn Rankine, who, sparing no trouble to afford the clearest conceptions of the meanings of the terms he employed, might also be said to have framed the modern English nomenclature used in the best works on applied mechanics.

The existing confusion is, notwithstanding, neither inconsiderable in itself nor in its consequences. As Mr. Price observes, in the course of his work on "Statics and Dynamics":—"The leading principles of theoretical mechanics, in themselves clear and distinct, have been so much obscured by ambiguity and indistinctness of language, that there is no subject on which more erroneous and confused notions are in existence." He cites as an instance the word "force," which is, of course, in continual use in works on mechanics, the science being itself often called the "science of forces." But what does the word "force" definitely mean? Will anyone give an exact definition of it; a definition which will be correct when the word is applied to express "the cause of motion," "accelerating force," "effective force," "force lost," "force gained, "living force," "laboring force?" "In some of these various meanings it indicates effect, in others it indicates cause." The confusion herein evinced is regarded by Mr. Price as "the reason why the principles of mechanical science, or the science of motion, are so imperfectly understood." To take again the word motion. "It is frequently used synonymously with the word velocity." In this way "momentum" has been called "quantity of motion," though in reality it means "quantity of velocity." To these instances we may add that of the abuse of the term "power." Even in standard works on mechanics and natural philosophy it is employed with at least four distinct meanings. In the instance of the compound term "mechanical power" it means a simple machine, such as a lever, a pulley, or a screw. It is next used to express the force acting on a simple machine of this kind, and by which another force—the weight—is to be overcome. In its most general acceptation the word "power" is frequently employed to indicate the ability of agencies to produce motion and to perform work, such as when speaking of steam, water, or animal power. And, fourthly, the word is applied as in the term "horse-power"—or more grammatically, a horse's power, and horses' power—to indicate the work, by reference to a standard, which can be done in a given time by a prime mover, and thereby afford an expression of the relative value of any prime mover.

If a misuse of these terms is unhappily very current in works of a high scientific theoretical character, this is still more the case in books on applied mechanics and on natural philosophy, and more especially in those intended to popularize scientific results, in which the authors are not, so to speak, controlled by strict mathematical formulæ. There are many works—even of great importance in themselves, and written by authors of naturally great abilities but of no mathematical training—in which we find the abuse of such terms carried to its highest degree. A flagrant offender was the late Dr. Faraday. To his genius for experimenting and observation he had not added any mathematical knowledge, with its attendant clear ideas on "force," "motion," "work done," "*vis viva*," "accumulated work," "momentum," and so on. In this way he gets to be obscure and confused the instant that he quits his fine descriptions of his beautiful and ingenious experiments, and attempts to think out the remoter causes of the phenomena he observed. In his lectures, for instance, "On the Conservation of Force," delivered about fifteen years ago—and when, therefore, he was at the zenith of his fame—at the Royal Institution, he tries to show that our received notions of that force are unsatisfactory. Now, here is an essentially mechanical subject, requiring the most severe and strict treatment, and yet Faraday uses scarcely a single one of the words by which the fundamental notions of mechanics are expressed, in any distinct meaning. How different is the treatment of the same subject by Professor Helmholtz, the German physiologist and mathematician, and not only in the original German, but also in the translation in "Taylor's Scientific Memoirs." Faraday

calls the force of gravity—or the force the manifested nature of which has been the most studied of any force—"a case of power." He speaks of "the nature of a power" as gravity, heat, etc.; and then, again, he calls gravity, heat, magnetism, etc., "powers" or "forms of force," just as if gravity and the other real forces were of the same nature as heat and electricity. Heat is, as Faraday himself says—according to the most probable assumption—"a motion" of the particles of matter. Now if —in accordance with the best writers on mechanics—we define force as that which produces motion, then it is clear that gravity, as a force, can produce that mode of motion termed heat. On the other hand, it is just as clear that heat cannot produce gravity, and it is obvious that no force at all can ever be *converted* into motion. This would be equal to saying: "A cause can be converted into its effect." But the mode of motion termed heat can be converted into the modes of motion of the molecular atoms termed electricity or light —or into any corporeal motion, as in a prime-mover.

As another instance—scarcely less noteworthy than that of Faraday—may be mentioned Mr. Justice Grove, of battery fame. We allude to his use of terms, in his much-admired and justly-celebrated lectures "On the Correlation of Physical Forces." But he is by no means so obscure as Faraday, and rather misuses strict scientific mechanical terms in a colloquial sense. He speaks of heat as a mode of force, all the while that he is trying to prove—and does indeed prove—that it is a mode of motion. But he does not go to the length of saying that heat is a force. He only means heat has a force, or in other words, that heat is able to produce motion—as in the steam engine—and generally by expanding bodies. In fact Mr. Grove uses the words force and power in their colloquial and physical, and not in their strict mathematical meanings. But even in works of this caracter both reader and author would evidently gain enormously from clear definitions in accordance with exact works on pure and applied mathematics. Any engineer would be better prepared to read any formulæ in which each symbol represented an exact conception. In fact, any work would be doubly raised in value if both author and reader were only accustomed to associate one clear and definite meaning to any one term.

The writings above cited were not directly addressed to engineers, and therefore the slips of their distinguished authors are to some extent excusable. But this cannot be said for words appealing directly to the engineering public. In his certainly physically great work on shipbuilding, Mr. J. Scott Russell does not, to say the least, use a very distinct mechanical nomenclature, and his ideas of dynamics are of a very questionable character. He has a great fondness for words like "power," which have no very exact and definite meaning. He uses the term "power" for "force," "work done," "prime-mover," "*vis viva*," and so on; and we cannot say that he is absolutely wrong, because we cannot say that we absolutely know what he means. But he is at least obscure when he speaks, as he does, of the "momentum" of the particles of water in motion exhausting itself by moving on again and over the water. To speak with precision, the words "*vis viva*" should have been used instead of momentum, as it is *vis viva* that overcomes resistance. Mr. Scott Russell also speaks of the "mechanical power" of a wave which is employed in wave-genesis. It would have been truly correct to speak of the *work* which has to be done to produce the *vis viva* of the wave motion.

Again, the late Canon Moseley, in his ingenious "Illustrations of Mechanics," writes of "Momentum, or the Force of Motion," and, nevertheless, defines force as "that which causes or destroys motion."

As an instance of an unphilosophical and illogical definition, may be cited the misuse of the word *inertia*. In all the older books it is called a force—force of inertia—*vis inertiæ*—an expression, indeed, to be found in Professor Gordon's "Syllabus of Lectures on Applied Mechanics," delivered at the University of Glasgow. Even the late learned Professor Weisbach illogically speaks of "the force of inertia" (*die Kraft der Trägheit*) "which appears with the changes of velocity and directions of bodies in motion." ("Lehrbuch der Theoretischen Mechanik.") But inertia is nothing else but a property of matter, and not a force. It would be just as correct to say that "Death is a force," that "the inertness of organic matter in the absence of vitality, is a force," as to talk of *vis inertiæ*, "the force of inertness." When inertia enters into any formula it is then simply the "mass" of the given body. It is in this sense that

Professor Gordon's successor at the University of Glasgow identified the words inertia and mass by saying the "mass of a body," *or* "its inertia." A very common shortcoming, not exactly a mistake, is often made by measuring the mass of a body by its weight in general. This occurs all through the dynamical formulæ in Professor Müller's work on "Natural Philosophy;" and even in the last and sixth edition, "mass" is again often erroneously defined as "anything which affects our senses." But it will be obvious that mass, considered independently of a force, cannot effect anything. This definition of "mass" is also to be found in Todhunter's "Mechanics," and other less important works. Our attempts at clear definitions and explanations of these questions will successively reappear under the titles respectively of—(1) "Motion, or Velocity and Acceleration;" (2) "Force, Mass, *Inertia*, and Momentum;" and (3) "Work Done, Accumulated Work, or Kinetic 'Energy,' and *Vis Viva*."

Having considered the motion of bodies, and defined velocity and accleration, we shall now examine the causes by which these effects are produced. On giving a ball, for instance, lying on a plane, an impulse, it begins to move, and in the absence of friction and atmospheric resistance it would move on with the same velocity during all eternity. But if, instead of a single impulse, the body gets a second, a third, and so on, always in the same direction, the velocity is continually altered and increased. The force of gravity, which may be considered as acting by impulses at infinitely short intervals all equal in intensity, thus affords a familiar instance of a uniformly accelerated or a constant force. The ball that received only one impulse would only move on with the velocity due to that impulse, but when acted upon with a constant force its velocity is also constantly accelerated. The truth that a body cannot by itself change either its state of motion or its state of rest—or the principle of inertia—seems so manifestly obvious as to be scarcely worth a statement. But this simple truth had to be established by a Newton. Such a great thinker as Kepler, for instance, believed that the planets were propelled round the sun by long invisible arms, or also by whirpools—*Wirbeln*. As a proof, however, that this principle of inertia is not popularly so well understood as it ought to be, we feel confident that many will be surprised to hear that, leaving out the resistance of the air, there is only one force acting on a cannon ball in motion—the force of gravity. On its leaving the barrel of the gun the action of the powder simultaneously ceases, and what carries it forward is its inertia, or its want of inherent capability to come to rest. It would therefore, in the absence of gravity, move forward in a straight line for ever, but gravity, continually acting upon it with a constant force, the direction of which does not coincide with the direction of the motion, changes its path from a straight line into a curved one, and alters its velocity. This instance also shows that any alteration of direction is an effect of force. And this must occur whenever the direction of the force does not coincide with the direction of the motion.

What is said about the accelerating action of forces is only true for such forces as act continuously during finite times. These principles, therefore, do not bear upon impulsive forces that act only during a single moment, or during an infinitely small time. We find that any force requires a certain time for its action, and that no force can be considered as acting during no time at all. For instance, the explosive force of gunpowder acts during a time which, however short, can nevertheless be measured, and therefore the force imparts an actual acceleration to the projectile during all the given time that the ball moves in the barrel. If the explosive force of gunpowder were instantaneous there would be no necessity for the considerable length in relation to its bore of any gun barrel. From the instant it leaves the muzzle the force ceases to act on the projectile, which would move forward with a uniform unretarded velocity, did not other independent forces, such as gravity and the resistance of the air, at once begin to act upon it.

The action of the gases developed in a gun on its ball will aid us in explaining the term mass, as used in all dynamical calculations. The notion of mass is one of those more difficult to be assimilated by the ordinary student, and may be regarded as the dynamical *pons asinorum*. Let us suppose two guns, of equal calibres, burning the same amount of powder, but charged, one with a 50 lbs. shot, the other with an elongated projectile weighing 100 lbs. The equal charges of powder act on the same piston areas, and the forces hence are quite

equal; but, nevertheless, their effects, apart from friction, are quite different. The spherical shot receives twice the velocity of the elongated projectile. At whatever spot of the universe we fire off our two guns, whether at the level of the sea or the bottom of a mine, where the force of gravity is greatest, or at the top of Chimborazo, where the force of gravity is least, or even if we fire them off on a planet with less attraction than our earth, the initial velocity of the lighter projectile will double that of the projectile having twice as much mass as the other. It is, therefore, clear that the mere attraction of the earth on a projectile, generally expressed by weight, cannot be the cause of the different effects which the same forces produce. The truth is, that the greater the velocity of the ball weighing 50 lbs. on the earth's surface is not due to its smaller weight, but that the different weights due to the earth's action, and the different velocities due to the gunpowder's action, are consequences of one and the same cause. The cannon ball has a smaller mass than the elongated projectile, or, in other words, it has less matter upon which the force has to exert itself. Having fewer particles, the amount of its inert matter is proportionately less. In common life this is expressed by saying that the one body has less weight than the other; it is also often said that the one body has less inertia than the other. Both these expressions are incorrect in a scientific sense. We should always say that the one has lesss mass than the other. Mass is by no means identical with weight. The weight of a body expresses the magnitude of the force with which gravity acts upon it, or with which the attractive force of the earth seeks to draw it to the earth's surface. The weight of a body, therefore, necessarily depends upon its mass, the heaviest body having always the greater mass. But there is this essential difference. As matter is indestructible, through whatever mechanical or chemical changes it may pass, the inert mass of a body is also indestructible. But the weight, on the other hand, of the given body changes with its distance from the earth's centre, and will, therefore, vary according as it happens to be at the sea-level, or on a high mountain, or in an elevated balloon, or also on a planet with a smaller or larger mass than that of our earth's. Mass itself is unchangeable; but the same spring balance carrying the same body will be pulled down further at the poles of the earth and at the level of the sea, than at the equator or on the top of a high mountain.

As the idea of mass is of a rather abstract kind, while at the same time absolutely indispensable, we will look at it from another point of view. That which constitutes bodies, and upon which forces act, is called matter; and in mechanics all matter is of the same nature. Let us now suppose that any given body, and likewise the given force acting upon it, are divided into any equal number of parts. If we now apply to each separate part of the body one of the equal parts of the force, each separate part will be accelerated by this fraction of the force in exactly the same way, and the separate parts will move together as if the whole force were acting upon the whole body. But if, on the other hand, we leave one-half of the body at rest, and apply the whole force to the other half of the body, then this half is now accelerated by a double force, and it will move with an acceleration double as great as in the first case. The moving body has now exactly half the mass of the whole given body, and by thus halving the mass the acceleration is double.

This is true for all forces, and we may say that the acceleration which a force imparts to a body varies directly as the amount of the force, and inversely as the mass of the body upon which it acts, viz:—

$$\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}.$$

And from this it follows that:—

$$\text{Force} = \text{mass} \times \text{acceleration},$$

and

$$\text{Mass} = \frac{\text{Force}}{\text{Acceleration}}.$$

In the above formulæ we have now a means for ascertaining the mass of a body. If we know the acceleration produced by a given force, and know the amount of that force, its ratio gives the mass. The most convenient force for the purpose is the force of gravity, as its amount is measured by the weight of the body. Therefore:—

$$\text{Mass of a body} = \frac{\text{Its weight}}{\text{Acceleration of gravity}}.$$

For practical purposes the acceleration imparted by gravity to a body on the earth's surface may be regarded as constant, and it is equal to 32.22; that is to say, a falling

body obtains an increase of velocity, under the action of gravity, of 32.22 ft. at the end of one second; so that we have, taking the reciprocal:—

$$\text{Mass} = .031 \times \text{weight}; \left(\text{as } .031 = \frac{1}{32.2}\right).$$

If we take, for instance, a body weighing 20 lbs., the mass is $=.031 \times 20 = .62$ units of mass. If the acceleration of gravity be assumed to be unchangeable, then the mass of a body is exactly proportionate to its weight, so that the weight is the measure of the mass of a body, and the greater its weight the greater its mass:—

$$\frac{\text{Mass of body A}}{\text{Mass of body B}} = \frac{\text{Weight of body A}}{\text{Weight of body B}}.$$

It must be well understood that this unit of mass is "a quantity proportional to the unbalanced force which is required to produce a definite change in the motion of the body in a given interval of time." It is a certain combination of weight and acceleration required to facilitate dynamical calculations. The unit of mass is not the same with all authors. Some measure mass directly by weight, but it is now generally accepted to measure the mass of a body by its weight divided by the acceleration of gravity. If a body were allowed to fall on a planet where the attraction of gravity would produce an acceleration of only 1 ft. per second, instead of 32 ft., then its mass could be expressed directly by its weight.

The following recapitulation will make the subject quite clear:—

32.22 is a number expressing the velocity in feet of a body after it has been falling during one second.

32.22 is a number expressing twice the distance in feet through which a body falls in one second.

32.22 is a number expressing the weight of the British unit of mass in absolute measure.

32.22 is a number expressing by the British unit of force the weight of 1 lb. at London.

32.22 is the British unit of force.

Of little scientific use or value is the term "momentum of a body"—an expression very often, and much too often, loosely used for *vis viva*, or accumulated work. As we have stated, an impulse once given to a body could produce an effect for ever, and this effect is sometimes measured by the product of the velocity into the mass of the body, or its momentum. It is, therefore, a measure for the "quantity of velocity" imparted. But it is very seldom that this measure of the effect of a force is convenient, and it is very seldom it can be applied accurately. It is in general preferable to measure the effect of a force by the work done and by the work accumulated in the moving body, which is measured by its *vis viva*, or the product of its mass and the square of the velocity.

ENGLISH IRONCLADS.

Written for Van Nostrand's Magazine.

We have a sea coast of unusual length, the greater portion of which is entirely without adequate means of defence, and we have a navy which at present is very weak, and which would take a considerable length of time to put in fighting condition. Under such circumstances it is at least interesting for us to consider the strength of a great European naval power, and to observe the struggles by which that power has arrived at the present results in naval architecture. The last number of the "North British Quarterly Review" possesses an able article which clearly and quite impartially describes the radical changes in ships of war made during the past few years. At as great a length of time as fifty years ago, the introduction of guns capable of firing shell horizontally, made some few observers predict a revolution in the construction of war ships. It was noticed that the artillery was being increased in destructive power, while the vessel's capabilities of resistance remained the same as in the days of solid shot. A French officer, Gen. Paixham, was probably the first to point out the proper method of protecting wooden ships; sheathing them in a plating of iron would cause the shell to explode outside the vessel's side, and by these means he thought that the danger of shells exploding after burying themselves in the ship's side would be avoided. His plans were examined into by the French Government, and after much discussion were finally put aside as impracticable, and for twenty or thirty years no

radical improvements in the means of protection were made. From the year 1821, when Gen. Paixham made the suggestion, to the year 1859, much, however, was done towards the perfecting of vessels, both for the navy and the merchant service. Steam propulsion had gradually proved itself successful, and iron ships were being built in large numbers; but, after trials, the latter were proved unable to resist shell, and they were supposed only to be fit for the merchant service. Although the honor of producing ships sheathed in iron is supposed to belong to the late Emperor, it is a fact that Mr. Stevens, of Hoboken, was the pioneer. This vessel is not finished at the present time, but her construction was commenced as far back as 1844, or thereabouts. The first European ironclads were French floating batteries, built in 1854, and were intended for attacking land fortifications. Their plating consisted of 4 and 4½ in. plates of solid iron, extending a few feet below the water line. Although these batteries were a success, they were very unseaworthy, and it was still believed that large ships could not carry iron armor and retain their sea-going qualities. But the French Emperor thought differently, and, with the aid of M. Dupuy de Lôme, he commenced the solution of the problem. In 1858 two vessels were on the stocks, and before the close of the year another was commenced. One fighting deck was considered sufficient, and the weight thus saved was utilized in the shape of armor extending 5 or 6 ft. below the water line, and about 4½ in. in thickness, a sufficient protection against the guns then carried. Meanwhile the English had done nothing toward constructing armored ships, and a year was allowed quietly to pass by. At the end of that time the popular clamor demanded that some action be taken. The Admiralty never had given a good reason for the delay, and it was known that Mr. Scott Russell had even presented the plans for an armored vessel, but that no action was taken upon his proposals. No explanation was possible, and the gravest censures were passed upon the conduct of the Board of Admiralty. At last an armored vessel was commenced, and during her construction a change in the Board rather hindered than facilitated the improvements; but before the close of 1859 a sister ship was ordered to the Warrior, to be called the Black Prince, and two other vessels of less size—the Defence and the Resistance. All of these ships were contracted for with private parties, while the Government yards were busy with constructing wooden vessels. The year 1860 saw no new ironclads under way, though in that time upward of fifty unarmored vessels were in progress of construction. During this time the French were pressing forward with energy, and had a war broken out between England and France at this time, there can be small doubt as to the result in so far as naval power went. Again, the English observing the state of affairs, a popular cry was raised, and the period of inaction was followed by one of unusual and almost fevered action. Money was given without thought, and the ingenuity and skill of the English was put into the work, who, with their already great experience in the construction of iron merchant ships, coupled with their great knowledge as seamen, soon made the scale of power turn in their favor.

Now commenced the war which still rages between plates and guns; as soon as a vessel was armored and considered impregnable, a gun was constructed of a size sufficient to pierce her plates; the next vessel was provided with armor to resist this weapon, whereupon a new and still larger, or more powerful cannon was constructed. From the coating of the Warrior, 4½ in. thick, the defensive shield has already reached in the Glatton, 14 in., capable of withstanding shocks from the 25-ton gun, at close range.

In 1861 Capt. Cowper Coles in England, and Mr. Ericsson here, broached the idea of mounting guns in a revolving turret. Experiments were made, proving quite successful, but nothing was done practically till the news of the engagement of the Monitor and Merrimac was received. Although our success with vessels provided with turrets had been great, they were considered in England as unseaworthy, and France being considered the most dangerous foe, the English designers determined still to adhere to the construction which gave them a superiority over the French ships of the same build. The Warrior, built in 1859, was an iron hull protected by 4½ in. plates, backed by 18 in. of timber, all this being on the outside of the hull proper. Bow and stern were unprotected, but divided into small water-tight compartments; this did not compensate for the lack of armor, and left the ship entirely unprotected about

the rudder head. She is 380 ft. long and weighs 9,000 tons, and under full steam makes fourteen knots. The next ship, the Minotaur, built in 1861, is simply an enlarged Warrior; she is too long, and is now considered to be unhandy, and lacks that ease in movement so important for war ships. Of broadside ships, the Bellerophon, built in 1863, is the next sample. She is only 300 ft. long, but carries very heavy guns, and has the power of firing at almost all points of the horizon. The Hercules, 1865, is slightly larger than the Bellerophon and carries eight 18 ton guns and two of 12 tons, but resembles the last ship in most points.

The Invincible, 1867, although being in many points superior to the Hercules, does not carry such a heavy armament; but her design being better, everything is utilized, and in fact she is a better ship in capabilities, if not in size. Shortly after our Monitor the English experimented on a ship with turrets, cutting down a line of battle ship for the purpose. This vessel, the Royal Sovereign, was so successful that a determination to test the turret system resulted in the Admiralty building the Monarch, and Capt. Coles in connection with Messrs. Laird, the Captain. Of the latter vessel, her loss with almost all on board in September, 1870, is too recent to need description. Both of these vessels carried sail, and it was now determined to construct turret vessels, relying solely upon their steam power. Of this class the Devastation, designed by Mr. Reed, is an example. Before her came a vessel built for the defence of Melbourne, the Glatton. This name is familiar, on account of the recent trials at Portland. She is a two-turreted vessel without masts or sails, and carries four 35-ton guns. For purposes of "ramming" two iron-clad ships have been built, the Hotspur and the Rupert. Only one or two of the heaviest guns are carried on these, their power of defence being great, while their power of offence, chiefly with the the ram, would under certain circumstances prove very great. Another subject is just at present agitating the councils of naval architects. Torpedoes, if successful, will make it necessary to arm the ship's bottom more heavily than even the part out of water, and the result may be, that the immersed portion will be the only part protected. But there is nothing as yet definitely determined about the offensive power of torpedoes in deep sea warfare, consequently any such sweeping change is only a matter of speculation. In naval construction, nobody can foretell with any certainty even the immediate changes likely to take place. We have to do the best we can to make ships as safe as lies in our power against the weapons actually in use, and trust that with the invention of a new offensive weapon, an invention for defence will follow.

THE COAL FAMINE—ECONOMIES AND REMEDIES.

From "The Engineer."

As since the publication of our last article on the coal question Mr. Mundella has moved for a Committee of Inquiry such as that we have asked for, we shall not revert here to the importance of a Parliamentary inquiry with a view to lay bare the real causes of the extortionate prices of coal, further than to recall to our readers a notable example of the value of an authoritative public declaration of the facts as to the prime cost and existing selling prices of coal. Early in the reign of the late Emperor Napoleon III. there was in Paris great dissatisfaction as to the extortionate price of coal gas. The public were quite at sea as to the grounds for this; none but the gas companies had any certain knowledge of the truth. A small but able and disinterested commission was decreed, from which the Emperor in effect demanded but a single question: "Tell me what should be the prime cost of the best gas that can be made in Paris—having regard to materials and gasmaking plant only, and irrespective of capital sunk in mains, etc., for distribution?" The Commission reported, and the mere authoritative statement of the enormous difference between cost and selling price, though ineffectually attempted to be gainsayed by the gas companies, was enough to enable the public to resist their demands, which were gradually dropped.

Rightly or wrongly, the opinion gains ground that the masters and men, to a certain extent, understand each other and "find themselves in the same boat." A small

output and enormous profit suits the coal-owner, high wages and idleness two-thirds of the week are sweet to the pitmen; all the rest of the body politic suffers; it finds itself in face of an impregnable and relentless monopoly, the poor wring their hands, the rich deplore in vain; trade and business are impeded, and the reflective look with apprehension at the too probable and not remote consequences.

If we must pay for coal more than twice its value, let us economize it rigidly and at once, is the very obvious advice that now fills every daily paper. Had we not better look this matter of economy right in the face, and by seeing to how very small an extent it is practicable immediately, or at all, rid ourselves of the chimerical notion that through it we have any chance of alleviation for the instant evil? The statement of Sir William Armstrong that only one-tenth of the coals consumed by our steam engines is transformed into mechanical power; that by moving forward into our room our open fire-grates; and by the substitution of the best designed engines and boilers in place of old and wasteful ones, a saving of one-half the coal now burnt for domestic use and for steam power might be achieved, have been repeated, commented on, and enforced as if they were a sort of coal gospel, and with the average amount of scientific ignorance, by the daily newspapers. In reality these statements are little more than barren generalities, useless and inapplicable to meeting the crisis before us. Few of our readers need be told that although it is a fact that M. Hirn proved that in a certain, said to be well constructed, engine, experimented on by him, one-tenth, or thereabouts, only of the heat of the fuel was transformed into mechanical energy, yet, in the present state of knowledge, the maximum margin for economy out of the wasted nine-tenths is very small indeed, even though we could work at immensely higher steam pressures, and could command everywhere and without limit a supply of condensing water at zero. It is impossible, by any sort of steam engine, to save more than one of the nine-tenths wasted. The conceivable saving of even that must remain for the science of a future generation. It is therefore but a specious delusion to tell the ignorant public that nine-tenths of all the coal burnt for steam power are wasted. Steam engines fixed and on land can be made to work with from 2 lbs. to 2½ lbs. of coal per indicated horse-power for a time, and by great care with even something less. At sea the minimum consumption may approach to, but can scarcely be maintained at this. What is the actual actual average consumption of all the engines of every sort in the country, or proceeding from its ports, is known to no one. It can only be guessed at. Taking bad and good together, the old wasteful engines of the Scottish or other types, consuming 5 lbs. to 7 lbs. per I. H. P., together with the now large proportion of well-constructed modern engines of all classes, we are disposed to believe the actual average to be not more than from 2½ lbs. to 4 lbs. per I. H. P. per hour. If, then, this be even approximately true, the *possible* saving in the existing state of knowledge is neither nine-tenths, nor yet even one-half, but about two-sevenths of the present consumption. Sir William Armstrong's former engines and boilers must have been of very exceptional badness, if by the substitution of good boilers and the Corliss engine he has been able to make 20 tons of coal do the work of 60 tons formerly. But even of those who work such wasteful engines and boilers, very few are so circumstanced as to be able suddenly to make any change. Work in hand, scanty capital, factory tenure, and a thousand other obstacles and difficulties, make it but too often the part of prudence to work on with known wastefulness, rather than attempt the difficulties, risks, or losses involved in radical change.

And so also as respects our domestic fireplaces and modes of heating and cooking; they are the gradual results of generations of adaptation. The great open hearth and *andirons* in which our forefathers burnt wood, slowly gave way, and with as little alteration as possible, to the grates for burning coal; they cannot be suddenly or largely altered, no matter what be the inducement in the way of economy. The immense middle and lower classes are the great coal consumers for domestic purposes; alterations in their living room grates involve money to be expended which they have not got, upon houses not their own, and for the sake of a saving by no means provable to them. A living room open grate delivers into the room nothing but some pure radiant heat, which probably does not represent one-twentieth part of the fuel consumed; but wherever the necessities of ventilation

and habit require open grates at all, very little of their waste can be avoided. There is nothing new in Sir William Armstong's suggestion of bringing forward the grates more into the room. In Lancashire for more than a quarter of a century grates have been in use made to circulate currents of air round the back or side plates of the grate and discharge it again into the room. Grate stoves oven are to be had everywhere which amount to moving the entire grate bodily forward into the room. But in small rooms space prevents any moving forward, even all other obstacles removed; and beyond all this, as a matter of fact—with even grate stoves of the best construction, radiating and emitting heat at all sides—this heating power, for a given consumption of fuel, is not increased in anything like the proportion of 2 to 1; and hence, were the proposal of merely advancing the open grate somewhat into the room otherwise practicable, the saving of fuel thereby would amount to nothing approaching one-half.

The reasons are obvious. In every open grate the vast mass of the heat is swept up the chimney. The radiant heat is only efficient so far as it comes from luminous fuel, and this additional heat radiated or evicted from the moderately-heated non-luminous surfaces about the grate, can add but little to the warmth of the room, for they cannot be heated above 200 degr. Fahr. without burning the dust floating in the air and otherwise injuring health. For cookery purposes much fuel might, in the richer houses, be saved were gastronomic science better spread and cookery prejudices overcome; but servants must have cheerful fires to look at as well as masters and mistresses, and are not content with comfortless "kitcheners." In the homes of the poor nothing can be saved of the fire they consume for their simple cooking; yet, could they be induced to use, and were in some way supplied with the stoves fitted at once for warmth and for cooking largely used in manufacturing Belgium, they could cook better, save fuel, and be better warmed; but by reason of worse ventilation would no doubt suffer more or less in health or sthenic resistance to the vicissitudes of weather and other hardships to which they are exposed.

The total vast consumption of fuel in Great Britain may be roughly divided under five great heads, viz., iron and other metallurgies, manufactures, including processes and steam power, steam navigation and other locomotion, domestic consumption, and exportation. Of these, in ironmaking—our great staple metallurgy—there is not much apparent room for economizing; in copper there is, but the trade is too ponderous for such a rapid change, even when economy is obvious. Railway locomotion presents no great field for economy. In steam navigation much has been achieved, but the great increase—the great and continual increase—in the number of mercantile steamships appears to more than swallow up whatever the marine engineer saves by better boilers and engines. In domestic uses, as we have said, there is no likelihood of any very sensible reduction in consumption, except what the pinching of exorbitant prices must for a time compel. Thus, on the whole, economization of our coal becomes in every direction more shadowy the more closely we regard it. Exportation alone remains as one element of consumption that at least is capable of being effectually dealt with; and not only the present anomalous state of the coal trade, but the indubitable concurrent running out of our national capital in coal itself, both point to this time as one in which the Legislature is fittingly called upon to reconsider the question of placing an export duty upon fuel. The evils—or some of them—of such a retrograde measure are obvious; but the real question is, May not the ultimate evils of the present state of things be much greater?

Some of our contemporaries enforce as their panacea for existing prices the extended adoption of coal-cutting machines. That subject in its important bearings would require a long article to itself. Meanwhile, let us just say, no thoroughly efficient and unobjectionable coal-cutting machine has yet been devised; and whenever one shall be, it will not dispense with the pitman to any very notable extent, or to one that will make coal-winning independent of strikes. But what if the coal-owner does not want it, and prefers his high price and small output—would he not put his coal-cutting machinery upon short time, just as the pitmen have put themselves upon that?

Our readers must not misunderstand us as denying the possibility of effecting economy in existing coal consumption. After a generation or two much will be effected; but the habits as to the use of fire

of a whole people, the result of ages, cannot be undone in a day. We, however, also desire to point out that the practical limits of possible economy are much narrower than many suppose they are.

Have we, then, no remedy whatever against extortionate prices in coal if so be that, as we believe, all talk about economy is in the present case but empty air? We believe there is one resource at least of a material kind, in addition to the moral effects producible by laying bare the actual facts by a Parliamentary Commission, and that is the importation of foreign coal. But whence and to what extent this can be done, and what would be its effects, are subjects too large to handle here, and we must reserve them for hereafter.

HINTS ON FORGING IRON.

From "Iron."

An interesting "blue book" was published some time since, containing much valuable information given to Government by the most eminent firms in the country. A brief summary thereof may not be devoid of interest and value, as these sources of information are not often applied to by, or accessible to, the general public.

With respect to the best mode of securing from deterioration the store of raw iron, the opinion is expressed that it should be kept under cover, and exposed as little as possible to the influence of moisture. The best iron is that which is most frequently worked, or which in the manufacture undergoes the greatest number of processes at a welding heat. But very superior iron, with the exception of charcoal iron, is produced from remanufactured scrap and old iron; and, in order to insure the most perfect workmanship in this important article, it is submitted that means be afforded in the dockyards for remanufacturing the whole of the suitable scrap and old iron which arises in the service. In some private establishments this is done with extraordinary care, and the result is a very superior article.

The cleaning of the scrap iron previous to manufacture is recommended to be done in the chain-cable cleaning machine as far as possible. By this means, not only will the scrap iron be perfectly cleaned, but the cleaning of the chain-cable will be facilitated by the increased attrition thus produced.

With reference to the means of producing sound smiths' work, the most fertile sources of defects which from time to time have beeen experienced are: (1) The original inferior quality of the iron; (2) Improper treatment in the forging; (3) Improper treatment of articles of smiths' work in actual service. With respect to the quality of the iron, that employed in the dockyards is generally of good quality, and only requires due care in its treatment to render the work produced therefrom equal to any legitimate duty required of it. With respect to the second cause of defects, namely, improper treatment in the forging,—as this head refers to a very extensive class of defects, it may be proper to regard it, first, with reference to the nature of the forging; and, secondly, to the kind of coal used in the operation.

It being most important that every condition necessary for the operation of welding should be in the highest state of perfection, this requires that the iron should be at the right welding heat, rather than over or under it; so that, if any slight delay or impediment arise in bringing the parts together, there may be, as it were, a surplus of heat to work upon; and next in importance to this is, that as little scoriæ, or oxide, or other foreign material as possible should cling to, or interpose between, the surfaces about to be welded. As the welding of iron is accompanied by its combustion, and by the production of an oxide in a melting state, we must altogether get quit of this interposing material, as, ere the two pieces are laid together, it has a tendency to form as rapidly as it is swept or wiped off. But, very fortunately, in almost every case, if due care be paid to the form and manner in which the surfaces are presented together, the instant the blows are given to the parts in question, the interposing scoria is forced out, and the then perfectly pure surfaces of the welding-hot iron are so brought into intimate contact as to unite together and form one mass. There is no department of the art of forging more important than this, inasmuch as, in the majority of cases of defective welding,

it is observed that the defect in question has arisen either from the scoriæ being shut up by means of improper forms of the surfaces, or that it has been insufficiently expressed from between the surfaces, for want of due energy in the blows of the hammer. That great attention should be paid to this is the more important and requisite, inasmuch as, in a great many cases, the system of "dab on" welding is unavoidable in the production of certain pieces of work; and as such "dab on" parts are generally subject to great and unfavorable strain, it is more than usually requisite to adopt the proper precautions, so as to secure the proper expression of the scoriæ, and the intimate union of the surfaces.

Secondly.—On the subject of forging it may be proper to refer to the kind of coal used in that operation. Much evil arises in this process from the risk of viscid and sulphurous scoriæ clinging to the surfaces of the iron, owing to the use of raw or impure coal as the material for the smith's fire. If the coal were of a pure quality, namely, such as contain nothing but carbon and its ordinary bituminous accompaniments, the evil alluded to would be less felt; but as all coal contains, besides earthy matter, more or less of sulphur, a class of evils arises which is of a very serious nature. When we attempt to weld together two pieces of iron which have been heated in a fire formed of very sulphurous coal, not only is the quality of the iron damaged by being rendered brittle, but also its surface becomes covered with a certain substance which, in a very remarkable degree, destroys that adhesive quality which accompanies iron when at a welding heat.

When this evil exists to excess, the parts will not unite, however much they may be hammered. But although such an extreme case as this is not frequent, yet it is a question of degree, and not of existence, so long as raw coal is used. It is therefore advisable for those fires which admit of it, slightly to carbonize the coal in a separate oven previous to use. This is the practice in most private establishments, where the quality of the smiths' work is a prime object. The practice should be discontinued of making notches in the scraps of two pieces of iron about to be welded together, as such notches afford a lodgment for scoriæ, etc.

Another extremely bad practice should be discontinued, namely, that of throwing a few fresh coals into a hollow fire on the hot iron, just before the heat is coming out. The use of air-furnaces prevents this.

It is recommended also to abolish cold hammering, unless the articles can afterwards be annealed, and to return all obsolete, unserviceable anchors to be worked up in the dockyards, into wrought iron bars, etc., under the steam hammers and rolls. The committee appointed to investigate the several matters relating to iron, etc. (including Mr. James Nasmyth), report that the result of their experiments clearly shows that very heavy strains even to the extent of the breaking strain (that is equal to the strength of the iron itself), and this even several times repeated, were found not only not to weaken the iron, but actually to increase its strength by every application. This conclusion is drawn from the following results of the several experiments:—

	Mean breaking strain.
1st fracture	33¼ tons.
2d "	35⅝ "
3d "	37½ "
4th "	40⅛ "

"These facts," the committee say, "appeared so important, and were so much opposed to the opinion of the best informed persons upon the subject, that in order to prove beyond all question, that the increased strength was due to the repeated previous strains, and not to the diminished length of the bars, we considered it proper to make experiments upon this point; we therefore took several bars of the same kind of iron, and of the same diameter, but varying in length from 10 in. to 10 ft., and found they were all equally strong. It may be proper to state the circumstances which usually attend the fracture of iron bars; namely, that considerable heat is evolved at the breaking place, and that the diameter of the bar is everywhere reduced, but particularly so at the place of fracture; but it is worthy of remark, that at the second and subsequent fractures of the bars, it generally happened that little or no heat was given out at the place of fracture, and that the general diameter of the bar was not again sensibly reduced, except in some instances, at the place of fracture."

No appreciable difference is caused by the process of galvanizing, as the following

abstract of numerous experiments proves. (The breaking strain in tons.)

Size of iron. Inches.	Galvanized tin iron.	Not galvanized.
1¾	53 375	52.833
1½	39.625	3 .375
1 3/8	27.375	27.06
1	19.25	19.25
¾	10 625	10.688
½	4.375	4 312

Such is a brief summary of the report, which was contributed to by information from twenty distinguished firms, and which has been drawn upon only where the information would probably be of general use.

We may say, in conclusion, that some of the results announced by the committee are somewhat remarkable. If they are right as to increase of strength resulting from the continued application of the breaking strain, what becomes of the modern doctrine of the "fatigue" of metals, and how are we to reconcile therewith the admitted action of the testing machine submitted to the Institute of Naval Architects in 1872?

BLAST FURNACES.

(*Continued from page 366.*)

(12.)—HEAT ABSORBED BY THE FUSION OF THE SLAG, THE DECOMPOSITION OF LIME, ETC.

Slags are of very unequal fusibilities. Sefström and Berthier have for a long time maintained that the bisilicates and even the trisilicates of lime, magnesia, and alumina, are more fusible than the protosilicates, and that in general the maximum of fusibility of earthy trisilicates always corresponds to that of the compounds of the bisilicates. For this reason the last formula is applicable where the presence of sulphur or the like does not call for an excess of lime. But it is obvious that not only the heat absorbed by the fusion of the slag, but also that of the smelting, should vary with its chemical nature. Plattner has shown the inequality in fusibility of the various silicates, by comparing it with that of alloys of platinum and gold. If fusibility varies with the composition of the slags, the same should hold as to their total heat. The slightly fusible protosilicates should require more heat than the bisilicates of the same bases, or than silicates that contain a certain proportion of alkalies and oxides of iron and of manganese. Hence the diversity of results existing as well for the slag as for the run of metal.

Minerae and Rousel found in the case of the very ferruginous slag from a cupola, 336 heat units: Rinman for a vitreous slag (from charcoal) sesquisilicate of lime and magnesia, 441 heat units, and in another case, 430; Gillot, for a vitreous manganiferous slag, with composition bordering on a bisilicate, 370 @ 380 heat units; Dulait and Boulanger for a slag from forge-pig, 443; from foundry-pig, 492. These two, like the most of these from coke-furnaces, should not differ much from protosilicates; but the first certainly contained oxide of iron.

M. Vathaire found for the slag to run No. 3, with coke, 550 heat units; and Bell obtained 572, though admitting the figure to be a little too high. We perceive that the bisilicate and manganese slags retain upon leaving the furnace only 370 @ 400 heat units; while the sesquisilicates approach 450, and the protosilicates may pass 500, when they contain neither iron nor manganese, but a large proportion of earthy bases.

Bell admits 550 heat units for the total heat of Cleveland slag to No. 3, due to a large percentage of lime and alumina.

In all cases the slag retains more heat than the run of metal, having a higher specific and latent heat. The latter, according to Rinman, reaches 120 heat units for sesquisilicates, while the metal attains only 46. But the diversity of results shows that special experiments are necessary for each kind of slag.

Very exact experiments have been made to determine the heat absorbed by the decomposition of the lime-stone. Favre and Silberman found 373.5 heat units for calcareous spar properly so-called, and 360.6 heat units for arragonite. Thus molecular condition has a certain influence upon caloricity. We may, however, assume in practice to the number 373.5.

The heat absorbed by the vaporization and decomposition of water remains to be considered. We assume, with Regnault, 606.5 heat units for vaporization properly

so-called. For decomposition, we have 29,003 heat units per kilog. of hydrogen liberated; that is, the heat produced by the combustion of hydrogen-yielding steam. Hence, $\frac{29003}{9} = 3{,}222$ heat units per kilog. of water decomposed. If the fusion of the slag absorbs the heat, the combination of silica and the bases probably disengages a quantity that we can measure.

(13.)—SENSIBLE HEAT CARRIED OFF IN THE GAS.

The heat taken in the gas is easy to calculate if their temperature and composition are known.

It is sufficient to consider separately each of the bodies composing the gaseous mixture. By their specific heat, as given by Regnault, we have, per kilog. and per centrigrade degree:—

For carbonic acid	0 217 h. u.
For oxide of carbon	0 226 h. u.
For nitrogen	0 244 h. u.
For steam	0.480 h u.

We shall find that their mean specific heat is in general about 0.237.

(14.)—HEAT LOST TO THE WALLS, ETC.

This consists of several portions:—the heat consumed by the water of refrigeration, determined without difficulty; the heat dispersed by radiation of the furnace walls; that taken up by passing currents of air; and that lost to the ground at the bottom. The two last cannot be measured; but experiment may find that due to radiation.

Bell made such experiments at Wear. He employed a parallelopiped-shaped copper vessel holding 19 litres of water, with all the sides except one enveloped in wood and flannel with layers of air intervening. He applied the uncovered face to the walls of the furnace, and thus determined the heat emitted per unit of surface in a given time. He found.

For the blast furnace at Wear, per kil. of run	186 h. u.
For heat taken off in the water in the tuyeres .10150 kilog. heated to 9°.16 Centig., or...	93 h. u.
Total	279 h. u.

To this should be added the heat taken up by currents of air and that lost to the ground. We shall find for total loss 300 to 400 heat units.

(15.)—DETERMINATION OF THE HEAT RECEIVED BY A BLAST FURNACE.

Neglecting the heat due to the combination of the elements constituting the run of metal or the slag, the heat *produced* is due solely to the transformation of carbon into a certain mixture of oxide of carbon and carbonic acid. This heat may be calculated, either after analysis of the gas, or by considering separately the zone of combustion and that of reduction where C O is transformed into CO^2.

Take the first method:

Making use of the notation of (7) we have y for the final weight of C O and my for that of CO^2,: hence $\frac{3}{7}\,y$ for the carbon in C O, and $\frac{3}{11}\,my$ for that in CO^2. But the carbonic acid contains b of carbon from the limestone: therefore, the carbonic acid produced by combustion contains only $\frac{3}{11}\,my - b$ of carbon.

The heat generated will be composed of the sum of the two products.

$$(1.)\ \frac{3}{7}\,y \times 2473 + \left(\frac{3}{11}\,my - b\right) \times 8080 \text{ heat u.}$$

As to the distribution in the two zones. A part of the carbon is changed to C O in the upper portion of the furnace; the rest descends and generates the oxide of carbon. Finally a part of the oxide of the total carbon coming from these two sources is converted into CO^2 by the oxygen of the mineral. Hence the heat in the zone of reduction is composed of the sum of the heats generated, (1°) by the partial conversion of carbon into C O in the upper part of the furnace; (2°) by the formation of carbonic acid under the action of the mineral.

It is easy to calculate the number of heat units. The 0.94 kil. of iron, forming 1 kil. of run were united in the peroxide to $\frac{3}{7} \times 0.04 = 0.403$ kil. of oxygen; and this oxygen is united to a proportion of oxide of carbon containing $\frac{3}{4} \times 0.403$ kil. $= 0.303$ kil. of carbon. If the carbonic acid thus produced were not partially recovered in C O, *i. e.*, if the furnace realized the *ideal* action, we should find in the gas at the mouth a weight of CO^2 containing $0.302 + b$ of carbon, b representing the carbon furnished by the limestone. But the gas at the mouth contains only $\frac{3}{11}\,my$ of carbon in CO^2; then $0.302 + b - \frac{3}{11}\,my$ is the carbon of that portion of CO^2 which is restored in C O; and as the carbonic acid burns a weight of carbon exactly equal to that which it already contains, this expression will also stand for the carbon converted into C O, in the region of reduction.

But as $a - 0.03$ kil., by (7), is the total carbon of the coke, less 3 per cent. yielded

to the iron, we see that the carbon consumed in the tuyere will be given by the difference,

$$a - 0.03 \text{ kil.} - (0.302 \text{ kil.} + b - \frac{3}{11} m o).$$

Thus the heat produced near the tuyere is equal to

$$(5.) \left\{a - 0.03 - (0.302 + b + \frac{3}{11} m y)\right\} \times 2473 \text{ heat u.}$$

As to the heat produced in the zone of reduction it amounts, as just shown, to

(1°) The carbon converted into C O by the mineral, that is

$$(0.302 + b - \frac{3}{11} m y) \times 2473 \text{ heat units.} \quad (6.)$$

(2°) The oxide of carbon transformed into C O^2 by the same mineral.

But the carbonic acid thus formed contains $\frac{3}{11} m y - b$ of carbon and corresponds to

$\frac{7}{3}\left(\frac{3}{11} m y - b\right)$ of oxide of carbon, giving by combustion

$$\frac{7}{3}\left(\frac{3}{11} m y - b\right) \times 2403 \text{ heat units.}$$

(7.) The sum of these three products should equal the number formed by the first method; that is reproduces the formula

$$\frac{3}{7} y \times 2473 + \left(\frac{3}{11} m y - b\right) 8080.$$

This is easily verified. The sum of (5) (6) gives

$$(a - 0.03) \times 2473 \text{ heat units.}$$

It is the heat produced by the total carbon of the coke transformed into C O. As to formula (7), which gives the heat produced by the formation of C O^2, we may write

$$\left(\frac{3}{11} m y - b\right) \times \frac{7}{3} \times 2403 = \left(\frac{3}{11} m y - b\right) \times 5607$$

and as

$$5607 = 8080 - 2473$$

$$\frac{7}{3}\left(\frac{3}{11} m y - b\right) \times 2403 = \left(\frac{3}{11} m y - b\right) \times 8080 - \left(\frac{3}{11} m y - b\right) \times 2473.$$

The sum of (5), (6) and (7) gives

$$\left(a - 0.03 - \frac{3}{11} m y + b\right) \times 2473 + \left(\frac{3}{11} m y - b\right) \times 8080 \quad (8.)$$

Which is equal to the total sum (4), for, by he notation employed in Eq. 1 of (7)

$$a + b - 0.03 = p$$

$$p - \frac{3}{11} m y = \frac{3}{7} y,$$

so that the co-efficient of 2473 in (8) reduces to $\frac{3}{7} y$ as in (4).

It will now be easy to compare the heat consumed with that received. It is sufficient to know the ratio $\frac{C O^2}{C O} = m$, and the values of a and b.

We now apply these formulas to examples.

(16.)—FIRST EXAMPLE.

This shall be the small furnace of the Clarence Works, 1853, Fig. 2. Height 14.60; volume 170; consumption 1450 kil. of coke, or 1318 kil. of pure carbon; 2240 kil. of mineral and 800 of flux. We have, then, per kilogramme of product

Carbon from coke, or a	1.318 k.
" from limestone, or $b = 0.12 \times 0.80 = 0.096$	
" total, or $a + b$	1.414
" taken by iron	0.030
" total of gas or p	1.384
By analysis, $\frac{C O^2}{C O} = m =$	0.387

With use of the formulas in (7) we get the the following results:

Weight of dry gas.

$m y = C O^2 =$	1.002 k.	Carbon 0.2735 $= \frac{3}{11} m y.$	
$y = C O =$	2.591	" 1.1105 $= \frac{3}{7} y$	
3.33 z or nitrogen	4,978		
Weight of dry gas	8.571	Total carb.	1.3840 $= p.$
Water from coke	0.051		
Weight of moist gas	8.622		

Weight of injected air.

Oxygen of dry air (z)	1.495
Nitrogen	4,978
Weight of dry air	6.473
Moisture 0.0062×6.473	0.040
Weight of moist air	6.513

Heat furnished by blast.

The temperature of this blast is 485° C. The specific heat of dry air is 0.2375, and as that of steam is 0.48, the mean specific heat of humid air is

$$\frac{0.2375 + 0.0062 \times 0.48}{1.0062} = 0.239.$$

This gives for the heat-units furnished by the moist blast,

$$6.513 \times 485° \times 0.239 = 755.$$

Heat produced in the furnace.

Heat due to C O^2:—

$$\left(\frac{3}{11} m y - b\right) \times 8080 = (0.2735 - 0.096) \times 8080 = 1434 \text{ h. u.}$$

Heat due to C O:—

$$\frac{3}{7} y \times 2473 = 1.1105 \times 2473 = 2746.$$

Heat generated in the furnace by 1.288 k. of carbon	4,180 h. u.
Hence, heat due to 1 kilog.	3,245 h. u.

The same kilogram completely burned, would produce 8080 h. u.; so that the heat really developed is only 0.40 of the proper calorific power of the coke.

Let us consider the distribution. The carbon burned in the zone of reduction is

$$0.302 + b - \frac{3}{11} m y = 0.302 + 0.096 - 0.2735 = 0.1245 \text{ k.}$$

The total carbon is	1,288
Hence that burned about the tuyeres is	1.655

and the heat produced here is

$$1.1655 \times 2473 = 2877 \text{ h. u.}$$

The heat in the zone of reduction is composed

(1.) Of the carbon converted into CO; or

$$0.1245 \times 2473 = 308 \text{ h. u.}$$

(2.) Of the oxide of carbon;

$$\frac{7}{3}\left(\frac{3}{11} m y - b\right) = \frac{7}{3}(0.1755) = 0.414 \text{ k.}$$

converted into C O^2, or

$$0.414 \times 2403 = 995 \text{ h. u.}$$

Summing up: in the zone of reduction

From burned carbon	308 h. u.
" " oxide of carbon	995 "
Total	1303 "
Heat in the zone or tuyeres	2877 "
Total heat produced	4180 "
Heat furnished by the blast	755 "
Total from all sources	4935 "

Let us compare with heat absorbed. This can be distributed under four heads:

(1°.) An element almost constant, comprising the heat taken up in the reduction of the mineral and the fusion of the metal, or [see (11)] 2314 h. u.

(2°.) The fusion of the slag, the decomposition of the limestone, etc. [see (12)].

Fusion of slag 1.610×550	= 885 h. u.
Decomposition of limestone 0.800×373.5	= 299 "
Vaporization of the water in coke 0.051×606	= 31 "
Decomposition of steam in blast 0.042×3222	= 129 "
Total	1344 "

(3°.) The heat from the gas (13). This escapes at a mean temperature of 452°. We find

For C O^2	1.002×0.217	for 1° Cent.		0.2175 h. u.
" C O	$2,591 \times 0.226$	"	"	0.5855 "
" nitrogen	4.978×0.244	"	"	1.2146 "
" water	0.051×0.48	"	"	0.0245 "
	8,622 k.			2.0421 "

Hence, for 452°;

$$2.042 \times 452 = 923 \text{ h. u.}$$

and for the specific mean heat of the gas:

$$\frac{2.0421}{8.622} = 0.237$$

a result found to be nearly constant at the Cleveland Works.

We have then:

(1°.) Heat taken in reduction and fusion of the run	2314 h. u.
(2°.) Heat taken in fusion of slag, limestone, etc	1344 "
(3°.) Heat carried off by gas	923 "
Total	4581 "
(4°.) Loss by walls, etc. (difference)	334 "
Total heat received	4935 "

(17.)—SECOND EXAMPLE.

We take the furnace at the Clarence Works (1866, Fig. 6, *ante*) of height 24.40 m.; interior capacity 330 cub. met.

Coke consumed per ton	1125 kil., pure carbon 1020 k.
Mineral	2240
Limestone	683
Slag	1520
Temperature of blast	485° C.
" " gas	332° "

We deduce per kilogram of product

Carbon of coke, a	1.020 k.
" " limestone $b = 0.12 \times 0683$	0.082
Total $a + b$	1.102
Carbon taken by iron	0.030
Total carbon of gas p	1.072

The analysis of the gas gives $m = 0.6865$.

The formulas of (7) give the following results:

Weight of gas.

$my = CO^2 = 1.195$ carbon contained $0.326 = \frac{3}{11} my.$

$g = CO$ ....1.740 " " $0.746 = \frac{3}{7} y.$

$3.33z$ (Nit.) $= 3.969$

Weight of dry gas..... 6.904 Total carbon ...1.072$=p$.

Water from coke.....0.029

Weight of moist gas . 6.933 k.

Weight of air injected.

Oxygen of dry air (z).....	1.192
Nitrogen.....	3.969
Weight of dry air	5.161
Humidity 0.0062×5.161	0.032
Weight of moist air	5.193 k.

Heat furnished by blast.

$5.193 \text{ k.} \times 485° \times 0.239 = 602 \text{ h. u.}$

Heat generated in furnace.

Heat due to CO^2:

$$\left(\frac{3}{11} my - b\right) \times$$

$8080 = (0.326 - 0.082) \times 8080 = 1971$ h. u.

Heat due to C O:

$$\frac{3}{7} y \times 2473 = 0.0746 \times 2473 = 1845 \text{ h. u.}$$

Heat produced by 0.990 k. of carbon.....3816 h. u.
Hence heat due to 1 k. of carbon 3854 h. u.

This gives for heat actually developed 0.48 of the calorific power of the coke consumed.

The 3816 heat units are divided between the two zones in the following proportion: the carbon burned in the zone of reduction is given by the formula

$$0.302 \text{k.} + b - \frac{3}{11} m y = 0.302 + 0.082 - 0.326 = 0.058 \text{ k.}$$

The carbon burned about the tuyeres

$$0.990 - 0058 = 0.932 \text{ k.}$$

and the heat produced in this region

$$0.932 \times 2473 = 2303 \text{ h. u.}$$

The heat disengaged in the zone of reduction comes from

(1°.) The carbon converted to C O or $0.058 \times 2473 =$..... ..... 144 h. u.

(2°.) The C O converted into CO^2 or $\frac{3}{7}\left(\frac{3}{11} my - b\right) \times 2403 = \frac{7}{3} \times 0.244 \times 2403 =$.....1367 "

Heat in zone of reduction .....1511 "

Hence, *en résumé*

Heat produced about tuyeres.....	2305 h. u.
" " in zone of reduction ..1511	"
Total heat produced by combustion.....	3816 "
Heat furnished by blast.....	602 "
Total heat received.....	4418 "

Comparing this total with that of the first example, we see that for the same useful effect, 517 less heat-units are required, and this difference is entirely in the region of the tuyeres.

The heat generated in the zone of reduction is 208 h. u. higher in the large than in the small furnace. We now find the value of the heat absorbed.

(1°.) For the reduction of the mineral and the fusion of the metal (see (11) *ante*)	2314 h. u.
(2°.) For the fusion of the slag, the decomposition of limestone, etc., by (12) *ante* we have :	
Fusion of slag 1.520×550	836 h. u.
Decomposition of limestone 0.683×373.5	255 "
Vaporization of water in coke 0.029×606	18 "
Decomposition of steam of blast 0.032×3222.....	103 "
Total.....	1212 "
(3°.) Heat from gas (13) $6.933 \times 332 \times 0.236$.....	545 "
Total.....	4071 "
(4°.) Loss to walls, etc.....	347 "
Total *received*	4418 "

(18.)—THIRD EXAMPLE.

The furnace at Ormesby (1867) Fig. 8. Height 23.20 m. Capacity 584 c. m. The minerals are from Cleveland. The production is 63 tons of Nos. 3 and 4, in 24 hours; corresponding to 9.2 c. m. capacity per ton of product.

Coke, per ton (or pure carbon 1017).....	1100 kil.
Mineral	2440 "
Limestone	625 "
Slag.....	1485 "
Temp. of blast.....	780°
" of gas.....	412°

Hence, per kilog. of product:

Carbon of coke (a).....	1.017 kil.
" limestone (b) 0.12×0.625 ...0.075	"
Total.....	1.092 "
Carbon taken by iron	0.030 "
" total of gas, p.....	1.062 "

The analysis of the gas gave $m = 0.542$.

The formulas of (7) give:

Weight of gas.

$m\,y = C\,O^2 = 1.000$ k. Carbon contained $0.272 = \frac{3}{11}\,m\,y$

$y = C\,O = 1.845$ " Carbon contained $0.790 = \frac{3}{7}\,y$.

3.33 z (nit). $= 3.743$

Weight of dry gas $= 6.588$ Total $1.062 = p$.

Water from coke $= 0.028$

Weight of humid gas $= 6.616$

Weight of injected air.

Oxygen of the dry air (z)	1.124 k.
Nitrogen	3.743
Weight	4.867
Moisture, 0.0062×4.867	0.030
	4.897

Heat from blast.

$4.897 \times 780° \times 0.239 = 913$ h. u.

Heat generated in furnace.

Heat due to $C\,O^2$:

$$\left(\frac{3}{11}m\,y - b\right) \times 8080 = (0.272 - 0.075) \times 8080 = 1592 \text{ h. u.}$$

Heat due to $C\,O$:

$\frac{3}{7}\,y \times 2473 = 0.790 \times 2473 =$ ..... 1954 "

Heat due to 0.987 k. of carbon	3346 "
Hence, heat for 1 kilog. of carbon	3593 "

giving for actual heat 0.44 of the heating power of the coke consumed.

The carbon burned in the zone of reduction is

$$0.302 + b - \frac{3}{11}m\,y = 0.302 + 0.075 - 0.272 = 0.105 \text{ k.}$$

That burned in the tuyeres $=$

$$0.987 - 0.105 = 0.882 \text{ k.}$$

and the heat generated here is

$$0.882 \times 2473 = 2181 \text{ h. u.}$$

The heat in the zone of reduction comes from

(1°.) The carbon converted into $C\,O$ or 0.105×2473	= 260 h. u.
(2°.) $C\,O$ converted into $C\,O^2$, or $\frac{7}{3}\left(\frac{3}{11}m\,y - b\right) \times 2403 = \frac{7}{3} \times 0.197 \times 2403$	1105
Heat generated in reduction zone	1365 "

En résumé.

Heat generated about tuyeres	2181 h. u.
" " in reduction zone	1365 "
Total	3346 "
Heat from blast	913 "
Heat, total received	4459 "

The absorbed heat is composed of:

(1°.) For reduction of the mineral and fusion of metal (11), the constant number	2314 h. u.
(2°.) For fusion of slag, decomposition of limestone, etc., (12).	
Fusion of slag 1.485×550	817 "
Decomposition of limestone 0.625×373.5	233 "
Vaporization of water in coke 0.028×606	17 "
Decomposition of steam of blast 0.030×3222	97 "
Total	1164 "
(3°.) Sensible heat of gas (13) $6.016 \times 412° \times 0.237$	646 "
Total	4124 "
(4°.) Loss by walls	335 "
Total heat received	4459 "

The details of the 4th and 5th examples are omitted.—Trans.

The results of the five examples are presented in a Table. (See page 456.)

The Consett furnaces are not strictly comparable with the other three. The ores were richer, being a mixture of hematites and calcined Cleveland oxides; and especially to be noted is the fact that the run is at lower heat (*moins chaude*), being Nos. 4 to 5 and not 3 to 4, as at Clarence and Ormesby. It follows that we should estimate a little less than 330 and 550 h. u., for the heat absorbed by the run and the slag. This circumstance explains the relatively low figures for loss by walls in the case of the Consett furnaces.

Let us compare the two furnaces of the Clarence Works differing only in volume and height; in all other respects identical. Hence, if the results are different, this should be due solely to the difference in height and capacity. It is to be remarked that the profile of the 1866 furnace is more *elancé* than that of 1853 (Figs. 2 and 6). With very different heights the bosh of the larger is only 15 m. larger than that of the smaller. The reduction would be less uniform in the small furnace, and this circumstance would cause a less economical working. Still the general experience with blast furnaces shows that this difference of pro-

file cannot have any great influence, when the mode of filling is adjusted to the section, as appears to have been the case at the Clarence Works.

The descent is slower in the large furnace. The capacities per ton of run are 8.6 m. and 5.6 m., respectively. But the difference in performance is due to this alone. In most of the old furnaces of Great Britain and the Continent, the interior volume does

NAMES.	Clarence Works, 1853.	Clarence Works, 1866.	Ormesby, 1867.	Consett.	Consett No. 4.
Interior capacity in cubic metres	m^3. 170	m^3. 330	m^3. 584	m^3. 266	m . 292
Height	metres. 14 60	metres. 24.40	metres. 23.20	metres. 16.80	metres. 16.80
Production in 24 hours	tons. 30	tons. 38.6	tons. 63	tons. 55	tons. 60
Capacity per ton	m^3. 5.6	m^3. 8.6	m^3 9.2	m^3 4.8	m^3 4.9
Nature of run	Nos. 3 to 4	Nos. 3. to 4	Nos. 3 to 4	No. 5.	Nos. 4 to 4.5
Mineral consumed per kil	kilog. 2.440	kilog. 2,440	kilog 2 440	kilog. 2 083	kilog. 2.083
Limestone per kil	0.800	0,683	0,625	0.412	0,406
Total carbon	1.288	0.990	0.987	1.0055	0.789
Carbon burned in zone of reduction	0.1245	0.058	0,105	0.096	0 113
Temperature of blast	deg. 485	deg. 485	deg. 780	deg. 454.5	deg. 718
" of gas	452	332	412	477	248
Value of m $\frac{CO^2}{CO}$	0.387	0.6865	0.542	0.502	0.623
Heat in furnace by kilog. of carbon burned	h. u. 3245	h. u. 3854	h. u. 3593	h. u. 3621	h u. 3816
Weight of blast	kilog. 6,513	kilog. 5 193	kilog. 4.897	kilog. 5 071	kilog. 3.751
Weight of gas	8.622	6 933	6.616	6706	5 161
Heat of combustion in zone of red. per kil	h u. 1303	h. u. 1511	h. u. 1365	h u. 1392	h. u. 1339
" " " tuyeres	2877	2305	2181	2249	1672
Total heat of combustion	4180	3816	3546	3641	3011
Heat from blast	755	602	913	551	643
Total received heat	4935	4418	4459	4192	3654
Heat in zone of fusion (sum)	3632	2907	3094	2800	2315
Heat absorbed by red. of mineral and fusion of run	2314	2314	2314	2314	2314
Do. by fusion of slag decomposition of limestone, etc	1344	1212	1164	800	762
Sensible heat from gas	923	545	646	758	303
Heat lost by walls	354	347	335	320	275
Total of heat consumed	4935	4418	4459	4192	3654

not exceed 5 to 6 cubic metres per ton; and this with often less consumption than at Cleveland; and the modern furnaces at Cleveland, measuring 10, 12, and 14 cubic metres per ton, do not consume less at equal temperatures of blast than furnaces of less capacity, provided the heights of the latter are appropriate to the more or less refractory nature of the ore and to the temperature of the blast. We see by the data of the Consett furnaces, that, even with a height 15.40, and a volume less than 5 m. per ton, and with certain ores, small consumption results. We conclude that it would be rash

to affirm in a general way, that the consumption of furnaces of large dimensions should be less than that of smaller.

The striking fact in the comparison of the Clarence furnaces is the difference of temperature of the gas--452 deg. in the small and 332 deg. in the large; then the difference in the value of $\frac{CO^2}{CO} = m$, which is 0.387 in the smaller, and 0.6865 in the larger. This small value of m in the smaller furnace denotes an unfavorable combustion of carbon, *i. e.*, an abundant formation of oxide of carbon at the expense of the carbonic acid due to the reduction. Each kilog. of carbon consumed produces

3854 h. u. in the large furnace.
3245 " " small "

609 difference.

A greater difference appears in the carbon burned in the zone of reduction: 0.058 per kilog. of run in the larger furnace, against 0.1245 in the smaller; which is therefore further from the *ideal* action.

	Per kilog. of run.	
The large furnace consumes	1.020 k of carbon.	0.990 burned. 0.030 taken by the iron.
The small furnace consumes	1.318 k of carbon...	1.288 burned. 0.030 taken by the iron.
Difference.....	0.298	

Again, the table shows a difference of total heat received amounting to 517 h. u. more for the smaller. This excess is furnished partly by the blast, partly by the combustion proper. Notwithstanding the equality of temperature, the blast gives more heat to the small than to the large furnace; since, consuming more carbon, it requires more blast.

The small receives from hot blast.....	755 h. u.
The large " " "	602 "
Difference	153 "
Total heat of combustion in first case ..	4180 h. u.
" " " " second case	3168 "
Difference.....	364 "

But in the higher furnace the heat directly generated in the zone of reduction, is more than in the smaller, and on the other hand the latter receives more heat from the tuyeres. The table shows a difference of 208 h. u. for the zone of reduction in favor of the higher, and of 725 in the zone of fusion for the other.

Now it is just this great heat generated in the zone of reduction, which constitutes all the advantage of a high furnace. The excess of 208 does not at all result from the greater quantity of solid carbon burned in the upper portion of the furnace. On the contrary the carbon consumed in the zone of reduction is only 0.058 in the higher furnace as against 0.1245 in the other; but instead of solid carbon, oxide of carbon is burned in the reduction zone of the larger furnace. Referring to (16) and (17), we see that the quantities of oxide of carbon transformed into carbonic acid are 0.414 in the small furnace, and 0.569 in the large; and the heat developed is for the large

By carbon burned 144 h. u.		In the small 3 .8 h. u.	
By oxide of carbon burned....	1367 "	"	995 "
	1511 "		1303 "

Hence the higher furnace approaches the *ideal* action more nearly than the other. Less solid carbon and more oxide of carbon is burned, and this difference exactly corresponds to the two values so different, 0.387 and 6865, of the ratio $\frac{CO^2}{CO}$. While the gas of the large furnace contains per kilog. of product, 1.195 k. of CO^2 to 1.740 of CO; that of the smaller contains 1.002 of CO^2 to 2.591 of CO.

With regard to the heat *received*, there should be an excess of 517 h. u. for the small furnace. We observe that the gas carries off under the form of sensible heat

923 h. u. in smaller furnace.
545 h. u. in the larger "

Difference 378 h. u.

On the other hand the fusion of the slag and the decomposition of the limestone also requires more heat in the smaller; because the excess of coke causes an excess of ashes, requiring an excess of flux. We have

1344 h. u. in the smaller.
1212 h. u. in the larger.

Difference 132 "

The sum of the two differences is 510; 7 h. u. are lacking; a loss due to radiation.

But these 517 h. u. represent but a small portion of the difference in consumption of the two furnaces, viz., that which corresponds to the sensible heat. There is a much more important part shown in the greater proportion of oxide of carbon in the gases at the mouth. The gas in the small furnace contains per kilog. of run, 2.591—1.740=0.851 k. more oxide of carbon than

that in the larger, or a difference in heating power of

$$0.851 \times 2403 = 2045 \text{ h. u.}$$

Adding 517 h. u. of sensible heat, we have a total of 2652 h. u. received by the small furnace more than by the other; 153 come from the hot blast, hence 2562 – 153 =2409 h. u. result from the excess of carbon burned; and the weight of the carbon itself is $\frac{2409}{8080} = 0.298$ k., exactly the difference between the consumption of the two furnaces.

Let us examine the causes of these differences. First, we recollect that the descent is less rapid in the large furnace. The ore does not in so short a time reach the region where the temperature is high enough to cause the reduction of carbonic acid by the solid carbon of the coke. At the level of the mouth the temperature is higher in the small furnace, 452 deg. instead of 332 deg. The temperature in descent should increase more rapidly, all other things being equal, in proportion as the mouth is further from the zone of fusion. Mr. Bell found in a furnace of 14.60 m.

At 2.97 m.	from	mouth,	cherry red.
" 4.80	"	"	bright red (8 to 900°).
" 8.32	"	"	point of fusion of copper, 1000° to 2000°.

In the furnace of Harghe 24.40 m., the bright red occurred at a depth of 7.90, and the point of fusion of copper at 15.80. Thus in the upper part of the large furnace there is a zone much larger, where reduction can go on, as in *ideal* action, under the sole action of oxide of carbon without consumption of solid carbon.

Herein consists the superiority of the large furnace. The gases are discharged at a lower temperature, so that their sensible heat is more utilized; again, a larger percentage of carbonic acid is formed, attended with the great advantage of a small consumption of solid carbon in the zone of reduction, while much heat is developed by the combustion of the oxide of carbon.

But shall we conclude that, in a blast furnace of given dimensions, the consumption is less in the ratio of the slowness of descent; or rather, that by the increase in capacity and height, the action is always rendered more economical? Is there no limit to this ratio of dimensions and production? Is there not for each ore and each run, a certain velocity and mean volume that gives a maximum of advantage?

In attempting to answer this question, let us first examine the case of small furnaces, finding out what experience tells us of the consequences of an extra-slow (*extra-lente*) action.

(22.)—INFLUENCE OF VERY SLOW ACTION.

At the Clarence Works, Mr. Bell had 6 small furnaces 48 ft. (14.60 m.) in height and 170 ms. in volume. A month gave an average consumption of 1,375 kil. of coke, when the daily production reached 35 tons. This was their normal action. For experiment less blast was furnished, and their production was gradually diminished, with the following results :

With a production of 31.3 tons, consumption was	1449 kil.
With a production of 29.4 tons, consumption was	1553 "
With a production of 26 tons, consumption was	1517 "

That is, the consumption increased with the slowness of action. But this single example is not conclusive; for even at 26.6 t. daily production, the action is not very slow, since each ton of product corresponds to only 6.50 m. of volume.

But here, in my judgment, are striking facts. I refer to the enormous consumption in the small blast furnaces (coke) at Pont-Evêque and at Vienne (France).

At Pont-Evêque, a furnace 11 m. high, and 36 m. in volume, produced in 24 hours, only 3.6 t. of white forge with a consumption of 2,000 kil. of coke per ton: this was an extra-slow action; since the interior volume corresponded to 10 m. per ton of white forge (*fonte blanche.*)

At Vienne, a furnace 10 m. high and 35 m. in contents, gave 4 tons of forge pig, with a consumption of 2,850 kil. of coke. But in this last case, there was less divergence from the ordinary action, the volume per ton not being higher than 8.75 m. The enormous consumption in all cases was accompanied with a small height.

Ebelmen was struck by the magnitude of these figures; but instead of seeking for the actual cause, he contented himself with drawing an erroneous conclusion, that blast furnaces with coke burn twice as much carbon as blast furnaces with charcoal. By reason of the more basic quality of the slag, the coke product may require (all other things equal) a slight excess of carbon; but for the same action and the same slag, more carbon is demanded of the

charcoal because of its great porosity, which favors its combustion by carbonic acid in the upper part of the furnace.

It is certain that the large consumption of the old furnaces at Vienne and Pont Evêque are due to their small heights and to the slowness of their action. Since that time all the blast furnaces in the valley of the Rhone have been increased to 15 or 16 m., and, because of their greater production, the interior volume does not exceed 5 to 6 m. per ton; and their consumption does not exceed 11 to 1,200 kil. for forge iron; at least when the coke is of good quality, not containing more than 10 to 12 per cent. of ashes and water.

It appears that not only small height, but also great slowness of action may augment consumption to a certain extent. And theory agrees with practice in this respect. Whether the action is slow or quick, it is evident that the temperature of the charges will always increase inversely as the height. With these conditions the ore is always a little reduced when it reaches the zone where the heat is already high enough to burn the carbon by the carbonic acid. Consequently the consumption will always be great in furnaces of low altitude. But too extreme cases may aggravate the evil.

If the action is too rapid—and in this case the ascending current of gas, as well as the solid descending current, both have an excess of velocity—sufficient time is not given to the oxide of carbon to accomplish reduction in the upper portions of the furnace. But if the action is too slow, the carbonic acid, remaining too long in the carbon, will re-form oxide of carbon in larger proportion. In these two cases further removal is made from the *ideal* action; more carbon is consumed and less carbonic acid is found in the gas.

Hence it is evident that between these extremes there should be for each furnace a *mean* velocity, corresponding to a minimum consumption.

(23.)—INFLUENCE OF EXCESSIVE HEIGHT OR VOLUME.

Let us consider the large modern furnaces at Cleveland. Their action is relatively slow, since each ton of product corresponds to 8, 10, 12, and even 14 cubic metres of volume.

But this slow action may in a certain degree be attended by as great inconvenience as in the case of small furnaces; the carbonic acid has time to reform oxide of carbon, although, because of the more gradual increase of the temperature in the higher portions of the furnace, this reaction of the carbon upon the carbonic acid is much less energetic than in case of lower altitude. But in this case also it is clear that there must be a mean corresponding to minimum consumption.

As regards the height, there is every evidence that it is limited by the physical condition of the ore and the fuel. If these are in small fragments, or friable; if they grind or settle of their own weight, a certain height may not be passed, because of the resistance which the compressed charges oppose to the introduction of the blast or the uniform and regular passage of the gas. But if the height is thus limited, so must the volume be. For a given height the shaft must be enlarged by increase of diameter, which makes the profile squat (*trapu*), and the distribution of gas is therefore less regular and the reduction less uniform.

In a word, all the conditions of action will be less favorable. A certain limit of height and volume may not be passed. If the shaft is broad and the distribution of the gaseous current not uniform, the action must be slower. This explains the fact, that the monster furnaces at Cleveland have, per ton of product, 8 to 12 cubic metres capacity; also the fact, that when more rapid action is attempted the working becomes irregular and the consumption large.

Let us show by examples that beyond a certain limit blast furnaces of extra dimensions offer no advantages. The profile of third furnace (Fig. 8) mentioned in the table above, compared with that at Clarence (Fig. 6), is relatively squat (*trapu*) and swollen. Notwithstanding the volume and production of this third furnace are almost double those of the other, it does not consume less for the same ores and run. There is, per kil. of run, 0.987 of carbon as against 0.990, and this notwithstanding a difference of temperature of the blast of 295 deg.; thus the consumption is identical, although it receives 311 deg. more by the blast. This is obviously an indication of less favorable action, a result shown by the figures in the table.

The ratio m is smaller 0.542 instead of 0.685; the carbon burned in the zone of reduction is more—0.105 instead of 0.058

k.; the heat developed is less—3593 h. u. at Ormesby, 3854 h. u. at the Clarence Works; the gases are discharged at 412 deg. instead of 332 deg.; the sensible heat taken off in the gas is 646 deg. against 545 deg.; the heat developed in the zone of reduction is 1365 against 1511 h. u., notwithstanding the excess of carbon consumed; and finally, the total heat of combustion is less in the Ormesby furnace, *i. e.*, 3346 as against 3816 h. u. All these facts show that the great furnace at Ormesby is less economic in work than that of the Clarence Works.

This may indeed be attributed to the form of the profile of the former; but this profile is a consequence of the increase of volume, and we are compelled to the conclusion that not only may the increase of the size of blast furnaces be of no advantage, but that it may be a positive injury.

The following facts, from Bell's memoir, support this conclusion: Bell has at the Clarence Works several blast furnaces of the same height—80 ft., but of volumes respectively, viz.: 11,500, 15,500, 25,500 cubic feet. There has been no appreciable difference in these three, except that the first appears to approach most nearly to the *ideal* action. The following are the values of m:

For several furnaces of 11500 c.f.	Furnace of 15500 c. f.	Furnace of 25500 c. f.
$m = 0.698$	$m = 0.560$	$m = 0.637$
0.647		
0.686		
Mean. 0.670		

Williams, the superintendent of the numerous furnaces of Bolckow and Vaughan, of 20,000 to 27,000 cubic metres capacity, 29 m. altitude (Figs. 7 and 9), all fed in the same way, maintains that he has not been able to discover the least economy in large furnaces. He concludes from long experience that, beyond 11,000 to 12,000 cubic feet of volume, the great furnaces at Cleveland have really no advantage in regard to the amount of fuel consumed. The furnaces at Eston are 15 ft. higher than those at the Clarence Works, and yet they do not burn less coke.

A final remark with reference to the furnaces at the Clarence Works and at Eston. I have already mentioned in (2) the three types at Clarence, and the two extreme cases at Eston (Figs. 7 and 9) of 15,000 and 20,000 cubic feet; there is an equal consumption of 1,125 kil. of coke per ton of product; but this equality is due in fact to the slower action of the larger furnaces, which require 11.7 and 14 cubic metres per ton, instead of 8 and 9 cubic metres. Hence if one wishes to get as much product proportionally from large as from small furnaces, he must certainly have a greater consumption; so that there is no superiority in very large furnaces. This alternative cannot be avoided. *The less production per cubic metre the greater consumption.* This same conclusion is warranted by the facts concerning the two blast furnaces at Ferry Hill. [See (2).] The first requires 9 cubic metres per ton, the second, 12 cubic metres. In spite of the great difference in height, the gas leaves the large furnace at a temperature which is only 6 deg. below that of the lower (191 and 197 deg.); and the consumption is sensibly the same in both, viz., 1,025 kil. of coke per ton of product in the lower, and about 1,000 in the other.

Now what cause shall we assign for this apparent anomaly in furnaces whose gases do not show more change in temperature in passing beyond a certain limit of height, viz., about 23 to 24 metres (under the conditions at Cleveland)? This question we shall next consider.

(To be continued.)

TRAIN-SPEEDS ON FUTURE TRUNK FREIGHT LINES.

By RUSSELL SAGE, Jr. C. E.

Written for Van Nostrand's Magazine.

I have read lately rhapsodies on the immense total or ultimate capacity and tonnage of imaginary double-track freight lines of the future, with trains moving each way at intervals of 3, 5, 6, 10, 12, 15, etc., minutes, and at speeeds of 5, 6, 8 and 10 miles per hour. Let us make a few calculations of the rolling-stock, train service, and sundry matters inseparably connected therewith, required at different speeds, and, comparing results, have a few words to offer as to economical speeds.

Given 100 miles of double-track freight road and an uniform yearly traffic that will require for

its transportation just one train of 25 cars each way every half-hour—required the rolling-stock, train-service and other facilities for train speeds of 5, 10 and 20 miles per hour.

There will arrive at each terminus 25 loaded cars every half-hour. Taking 365¼ days or 8,766 hours, to the year, we have 17,532 trains, or 438,300 cars, which at 8 tons per car give an annual traffic of 3,506,400 tons each way, or a total tonnage 7,012,800. No matter whether our half-hourly trains move at 5, 10 or 20 miles per hour, the total tonnage is the same, as are also gross earnings of freight rates constant for the different velocities. There is no particular wit or originality—and none is claimed—in the statement, that the amount of rolling-stock, train-service, etc., required to move this tonnage is enormously affected by the uniform rate of speed we may adopt for our half-hourly trains, and hence the amount of invested capital, interest and annual expenses. Allow 8 hours at each terminus for switching, minor repairs, unloading, reloading and making up each train for its return trip—an allowance I think that indicates prompt work, and small enough, keeping in view a miscellaneous traffic and considering every car throughout the year. After trying several methods I have settled on this basis, as the most equitable for working our train-men—viz.: 10 hours on and 10 hours off duty.

At 5 miles per hour.—Half-hourly trains will run at intervals of 2½ miles. For this speed we will run our locomotives similarly to our cars, viz.: 20 hours or 100 miles on the road and 8 hours off—severe as to hours but not as to miles. Each car and locomotive will make 100 miles every 28 hours or 313 trips annually—a total of 31,300 annual miles in 6,260 working hours on the road and 2,500 hours in yard or house. Each train-man will run 50 miles every 20 hours, or 21,900 miles annually—small as to miles, but it represents 12 hours on duty and in motion out of every 24 day in and day out. We shall have 40 trains each way constantly on the road and 16 trains constantly at each terminus; and shall require daily to just do our work:

2,800 Freight cars,	112 Locomotives,
160 Cabooses if each conductor has his own,	160 Conductors,
160 Engine-men,	160 Fire-men,
	320 Brake-men.

Our trains and business demand that these numbers, and no less, shall be ready for work daily—to insure which any one may add what he considers necessary for contingencies of wear, tear, breakage, delays, accidents and sickness; but whatever per cent. he may choose to add, the same should be added to the numbers in the other cases. Switching engines and yard men need not enter into our calculations since the number of trains arriving, departing, and standing at each terminus, are the same in each case.

At 10 miles per hour.—Half-hourly trains will run at intervals of 5 miles. Each car will make 100 miles every 18 hours or 487 trips annually—a total of 48,700 annual miles with 4,870 hours in motion on the road and 3,890 hours in yard. The locomotives in this case we will run 100 miles or 10 hours on and 10 hours off, the same as our train-men, and hence each will make 100 miles every 20 hours, or 438 trips annually—a total of 43,800 annual miles with equal hours on and off. We shall have have 20 trains and 20 locomotives each way constantly on the road; 16 trains or 400 cars, and 20 locomotives and sets of men, constantly at each terminus; and shall want daily to just run our trains:

1,800 Freight cars,	80 Locomotives,
80 Cabooses,	80 Engine-men,
80 Fire-men,	80 Conductors.
160 Brake-men,	

At 20 miles per hour.—Half-hourly trains will run at intervals of 10 miles. Still allowing our cars 8 hours at termini, each car would make 100 miles every 13 hours, or 674 trips annually—a total of 67,400 annual miles with 3,370 hours in motion on the road and 5,390 hours in yard. It would seem that having the opportunity we might keep our cars in motion at least half the time. I think so too; but this would compel me to figure them at 5 hours on and 5 off, whereas for a strict comparison, I ought and will adhere to 8 hours off. It might not, for a comparison, be fair to give cars 8 hours off in the other cases and restrict them to 5 in this; but the possibility of effecting this saving in time and cars is to my mind much greater in this case than in the others, and the note might as well be made right here, that the greater our speeds the more closely we may work our rolling-stock and train-men and hence effect a saving irrespective of the savings due to any speed *per se*. Running our locomotives and

train men as in the second case, viz.: 10 hours on and 10 hours off—each will make 200 miles every 20 hours, or 874 trips annually—a total of 87,600 annual miles, with hours of work and rest of course equal. As regards the men, I hold there is not much more labor or hardship in riding and attending to train duties 10 hours on a through freight, moving at 20 miles per hour on a double track, making no sidings and stopping only for coal and water, than there is doing the same duties 10 hours on a similar train moving at 10 or 5 miles per hour. Even if there is a small increase, the work then is simple, easy, far from excessive, and performed with 12 hours rest out of every 24. The possibility of working our men and stock liberally as to mileage is just the advantage and economy increased speed gives us. The locomotives I admit haul the same number of cars for twice the distance, or at twice the velocity in a given time, than they do in the second case, but the work is not excessive. There is no switching or shunting or siding,—simply a straightforward moving of 25 cars for 200 miles in 10 hours along the granted superior tracks of the future, stopping and starting the train not more than six times during the 200 miles, and then in the house 10 hours. Or you may run them 100 miles or 5 hours on and 5 off—the result is the same. In the first case we got 100 miles out of each engine every 28 hours, and to do that we had to force them in motion and at work on the road 20 consecutive hours out of the 28. Even if the mileage and speed made are double those in the second case, the work done and done in equal hours of rest is far from damaging or extravagant; and the possibility of getting this increased mileage easily, reasonably and safely, is the very point we are endeavoring to illustrate in practical figures. We shall have 10 trains and 10 locomotives each way constantly on the road; 16 trains or 400 cars, and 20 locomotives and sets of men constantly at each terminus; and shall require daily to do our work

1,300 Freight cars,	40 Locomotives,
40 Cabooses,	40 Enginemen,
40 Firemen,	40 Conductors.
80 Brakemen,	

Dropping the first case as too puerile—although speeds of 5 and 6 miles seem to find visionary advocates—and disregarding any percentage to be added for contingencies, let us note the difference in dollars between our results of the second and third cases, and then consider other facilities.

	Additional capital.	Additional Interest and expenses.
500 freight cars, say at $800.....	$400,000	$28,000
40 locomotives say at 14,000.....	560,000	39,200
40 cabooses, say at.. 900.....	36,000	2,520
40 enginemen say at. 1,200 per year	.....	48,000
40 firemen say at . 600 per year	.....	24,000
40 conductors say at 900 per year	.....	36,000
80 brakemen say at. 540 per year	.....	43,200
	$996,000	$220,920

That is, for the *rolling-stock and trainmen just sufficient* to move 7,012,800 tons of freight 100 miles annually with half-hourly trains, it will require an additional capital of $996,000 invested in perishable property, and an additional annual expenditure of $220,920 to transport that bulk at 10 miles per hour over the amounts for its transportation at 20 miles per hour.

Assuming that we ought to have round-house accommodations for all engines connected with our freight trains' service, then at 10 miles per hour we would require 40 additional stalls (20 at each terminus), which at $1,800 demand $72,000 invested capital and $5,040 annual interest additional to the same accounts at 20 miles per hour. The cost of the additional land and supervision is suggested. Increased machine-shop accommodations, facilities, force, stock of materials, and supervision for 40 engines, should be noted. It is a positive fact that 80 locomotives making the collective mileage 3,506,400 in 4,383 working hours will consume more fuel, oil and waste, than 40 locomotives making the same mileage in the same number of hours—or stated differently, that 1 engine making 200 miles in 10 hours will consume less than 2 engines each making 100 miles in 10 hours, or differently again, that 1 engine working 10 hours at 20 miles per hour will not require twice as much steam nor burn twice as much fuel as 1 engine working 10 hours at 10 miles per hour—the trains being equal. The 1 engine will burn more than 1½ and less than 2 times the amount of the other, but just where to fix the proportion between those limits is one of those estimates impossible to accurately determine. It would

seem, to fix it roughly at $1\frac{3}{4}$, to be more unfavorable than otherwise to my point; calling it $1\frac{3}{4}$, then if the total quantity of coal consumed annually by our 40 locomotives be represented by the number 175, that of our 80 will be shown by 200. Hence, as to the quantity of fuel, collective time becomes an element of large importance. The consumption of coal per 100 miles of freight trains on seven of our trunk lines East, Central and West, varies from $2\frac{1}{2}$ to 4 tons, depending upon the trains hauled, quality and kind of coal used, and the character of the different roads as to grades and alignments. For our average 100 mile road and 25 car trains, calling 1 ton of average coal equivalent to 35 miles, we shall consume say 100,000 tons; if this be taken to represent the annual consumption of our 80 locomotives at 10 miles per hour, then will the consumption of our 40 locomotives at 20 miles per hour under our proportion 175 to 200, be 75,000 tons; or if it be taken as the consumption of the 40 engines, then will the consumption of our 80 engines be 125,000 tons—in either case a difference of 25,000 tons of coal annually, which at an average price of $4 would give a difference in annual expenditures of $100,000. Adding the additional cost of getting these 25,000 tons into and out of our coal-sheds, and the probable increased storage capacity, we reach quite a significant item. Another item: With our engines 10 hours on the road and 10 hours in house, we have in the one case 80 and in the other 40 "fired up" every 20 hours—a difference annually of 17,530. I am assured that a dead engine cannot be "fired up" in condition to commence hauling a train for less than $2 average. Certainty $35,060 is an item. I hold without proof or argument that the collective, not the individual, wear, tear, depreciation and repairs of the 80 will be greater annually than of the 40 engines. Now as to our cars. Certainly 1,800 cars will require more shop facilities, supervision, and a larger amount of "stock of material" than 1,300 cars; and the collective, not the individual, wear, tear, depreciation and repairs of 1,800 cars making a certain collective mileage, will be greater than of 1,300 cars making the same mileage. Our 80 conductors and 80 cabooses will require the annual maintenance of 40 additional sets of train-tools and lanterns; the 40 that are constantly on the road at 10 miles per hour will, during winter, consume twice as much fuel, and during the nights, twice as much oil, as will the 20 constantly on the road at 20 miles per hour—items not insignificant annually. Sundry other items might be enumerated, but enough has been hinted to warrant us in assuming at least $1,200,000 additional capital invested mostly in perishable property and $500,000 additional annual expenditures.

As to repair of tracks I suggest: The annual mileage and tonnage of our 17,532 annual trains each way, and of each individual train, are the same in both cases; hence the question of repairs is solely any difference that may be due to actual speeds. I presuppose that the road-beds, tracks and equipments of our future trunk lines will be commensurate in character, permanency, and possible perfection with the magnitude of the traffic to be borne—else that same traffic would be ruinously expensive and well nigh impossible even at speeds of 10 or 8 miles per hour. The repairs of *road-beds* of such character, as perhaps of any of our present trunk lines like the Pennsylvania Central, cannot be greater for speeds of 20 miles than for speeds of 10 miles, if we except probable increased care in tamping ties—and the question to my mind is narrowed to wear and tear of rails—"The way or road is the foundation of everything else on a railway—It must be well kept and regularly ballasted"—True as a fact—not because somebody has said so—and, on any road of to-day or the future having an immense traffic, as true for train-speeds of 10 as for train-speeds of 20 miles an hour. Will any more or frequent ballast be required for one than for the other speeds, or any more ties used, rotted and renewed? Roll a load every 5, 10, 15, or 30 minutes over a stable surface absolutely smooth, and the wear of that surface will be appreciably the same whether the load moves at 10 or 20 miles an hour, other conditions being constant; and the question of the wear of rails of our future, as it is to-day of our present, roads, is practically and absolutely one of the stability and smoothness of track, and not infinitesimally of rates of speed *per se*. "The tons of traffic borne does not form a precise standard inasmuch as the wear is related—we will not say in what ratio—to the speed, the maximum weight upon a wheel, besides being closely related to the general condition in which the line is maintained, and

to that of the rolling-stock."* To every word of which we all heartily subscribe. Railroad managers and engineers, witnessing the present effects of speed, seem to have ignored or lost sight of truth and saddled the guilt on an innocent party, while imperfections of road, track and equipments, have escaped comparatively scot-free; let us have done with debating speed *per se* with all this increased wear and tear, and acknowledging the truth, build accordingly. "First of all there are the mechanical imperfections of the way. In consequence of these the resistances to traction [and of wear of rails] are much greater at high than at low speeds, whereas, except from the resistance of the atmosphere [and increased care in tampingties] there should be no difference at all. The friction [and wear of rails] on a railway as true as one of our Whitworth's lathebeds, would be the same at 60 as at 6 miles an hour, and it should be the steady aim of the railway science of the future to approach this degree of relative perfection."† This hint and certainty will 100, 50, or 25 years hence reduce my 25,000 tons of coal saved to nearer 40,000, and make the wear of rails more a matter of tonnage and of the load on wheels than of speed *per se*. If tracks must be rough and uneven, then positively speed becomes a ruinous factor in all track and train repairs for roads of to-morrow, as they are for roads of to-day; but the supposition and possibility of such conditioned roads for the future, with present experiences for guides, would be an absurdity. Absolute perfection cannot be reached, and right here we admit, rails of the future may and probably will wear out sooner at 20 than at 10 miles an hour, but not at any such ratio as we have on an average to-day. Shall we say $\frac{1}{8}$ or $\frac{1}{3}$? Let us be liberal and grant that, on even a comparatively perfect track with a relatively perfect equipment, and dead loads proportioned to live loads, and loads on driving and car wheels all figured to a minimum, as they must and will be in the future, our rails will wear out $\frac{1}{3}$ faster at 20 miles than at 10 miles per hour. I quote what I believe to be good authority: "Results of careful observations and records show that Bessemer rails have borne 95,000,000 gross tons of moderately slow traffic without being nearly worn out." What is meant by "moderately slow," I have no means of ascertaining; but will assume that 10 miles per hour defines it liberally. I find from numerous and trustworthy records that good iron rails have borne from 6 to 42 millions tons gross, and that steel rails are generally conceded to be equivalent to 6 iron rails; whence we would have 36 to 252 millions gross tons as the life of a steel rail, the average being 144 millions. Whatever be the safe tonnage life of Bessemer rails, I will keep liberally within limits and assume that the rails of the future will carry 95,000,000 gross tons safely to the point of renewal at a speed of 10 miles an hour. Calling the weight of each of our supposed trains 450 tons gross, we shall have 7,889,400 gross tons annually over each track, and a rail life of 12 years at 10 miles an hour. I notice that many have adopted an arbitrary standard of "speed tons," and one who professes to have investigated deeply furnishes the standard 220,000,000 tons at 1 mile per hour, as the life of a fair or good iron rail and then asserts the absurdity that at 2, 3, 4, 5, etc., miles an hour the rail under the same traffic will wear only $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, etc., as long as at 1 mile an hour.

Adopting this standard, then, for our traffic at 10 miles an hour, a good iron rail would last 2_{10}^{12} years, or a steel 16 years. Let us assume that under our traffic the rail of the future will not last 16 or 12 but 9 years at 10 miles an hour, and under our assumed rule 6 years at 20 miles an hour. Every 18 years the renewals in the two cases would come together, giving us one more complete renewal every 18 years for the 20 mile rate. Bearing in mind that track repairs and renewals at terminal stations and all stopping-places where switching and shunting are done, will be the same at any road speed—calling the value of the additional 200 miles every 18 years of old rails nothing--and assuming each renewal will cost $13,000 per mile, we shall have $2,600,000 additional track expenses every 18 years ($144,444 per year), against $9,000,000 every 18 years saved in rolling-stock, etc. Or calling the additional track repairs $150,000 per year, we would exhibit at least the yearly saving in expenditures of $350,000 for the 20 miles an hour speed over the 10 mile rate.

What do these figures signify? In the case cited—100 miles and half-hourly trains—

* Price Williams—from "Engineering."
† Zerah Colburn—in "Engineering" May 1st, 1868.

our $1,200,000 additional capital represents just that amount, no less, per 100 miles of road; or if trains move at 15 minutes intervals then must $2,400,000 be secured, or appropriated out of earnings per 100 miles of road; our $350,000 represents an annual interest or dividend on $5,000,000 per 100 miles of road, or an additional expenditure of $3,500 per mile; and if traffic should demand trains at 15 minutes intervals then will $700,000 saved be the interest or dividend on $10,000,000 per 100 miles of road, or, if squandered, an additional annual expenditure of $7,000 per mile; and all for the same tonnage and gross earnings at 10 miles per hour instead of 20 per every 100 miles of road.

I am no advocate of fast time for freight trains on average present roads. I have positively intended to be fair and honest in every statement, and do not care personally a picayune whether 100 years hence trains are run at 1 or 100 miles an hour, but I do care to let the above stand as a reason "for the belief that is in me," that trains on future trunk lines worked to their ultimate capacity will not be run at 6, 8 or 10 miles an hour, Tom, Dick and Josiah Quincy to the contrary notwithstanding; and that it is *not* "an axiom in railway economy that goods lines working up to their maximum number of trains must be lines of comparatively slow speeds in order not to absorb the profits in wear and tear"*—unless my English axiomatist* will exclude 6, 8, 10 miles an hour from his category.

The Hon. Josiah Quincy in a communication to the "Boston Daily Advertiser," date unknown, made the following hypothesis and calculation:

"Railway, 8 miles per hour and 2 miles space between trains; 7,008,000 tons each way: total tonnage capacity 14,016,000." That is substantially trains of 25 cars each way every 15 min.

"Railway, 10 miles per hour; 2 miles space between trains; 8,760,000 tons each: total tonnage capacity 17,520,000." That is 25 cars each way every 12 min.

"Railway, 10 miles per hour; space 1 mile between trains; 17,520,000 tons each way: total tonnage capacity 3,504,000." That is, trains of 25 cars each way every 6 min.

"Railway, 8 miles an hour; space half mile between trains; 28,032,000 tons each way: total tonnage capacity 56,064,000." That is substantially trains of 25 cars each way every $3\frac{3}{4}$ min.

"Railway, 10 miles per hour; space half mile between trains; 35,040,000 tons each way: total tonnage capacity 70,080,000." That is substantially trains of 25 cars each way every 3 min.

Whether these grand double-track freight roads of the future will or will not be able to move trains at intervals of 3, 6, 12 or 15 min., is not a matter now in question; an affirmative must assume as granted a great many things we know nothing about. Certainly such an immense traffic would indicate a corresponding tonnage and movement along all railroads, streets and highways crossing our line, all of which would have as much right to move at angles to us as we at angles to them; and hence to do any traffic at all, it would seem that all railroad, street and highway crossings of the future must pass over or under our line as well for their business as our own.

Mileage intervals are deceptive. One mile interval between trains may be in time 3 or 2 min. as the train-speed is 20 or 30 miles an hour; and while an interval of 1 mile might appear sufficient, an interval of 3 or 2 min. would to us of the present appear small. To my mind a mileage interval expresses nothing tangible. Consider Mr. Quincy's last example. If any mishap, slight, moderate or serious, should happen to a forward train, as it almost certainly will with his 480 daily trains each way, then, while his half-mile space might at first blush appear fair enough, the actual time interval of 3 min. would positively appear too small for the following train to discover the mishap and avoid mutual trouble. It certainly appears wiser and safer, to my way of thinking, to fix the time interval and let it govern the mileage space, than to fix the latter and let it govern the time interval. We of the present, so far as I have heard or read, do not run any trains nearer than 5 min., which 5 min. may indicate a mileage interval of $2\frac{1}{2}$, $1\frac{3}{4}$ or $\frac{5}{6}$ miles, as the train-speed is 30, 20, or 10 miles an hour. Whatever interval of time officials of the future may consider safe and proper, that interval decides at once the ultimate capacity or tonnage of their road—for whether their trains be run at 1 or 100 miles per hour there will arrive at and depart from each terminus or station one train

* Bridges Adams. The quotation is his fourth *axiom* of Railway Economy.

at every interval so adopted—no more and no less. The minimum interval between trains, and whence the maximum tonnage, will be determined entirely by the minimum time necessary for repairs; and while speed rates will not affect the maximum tonnage capacity one ounce, they will affect enormously the amounts of rolling-stock, train-service, etc., required for its transportation—and this is my very simple point.

As another illustration, let us consider briefly Mr. Quincy's last, and to my mind absurd example above.

Given a double-track freight road from Chicago to the seaboard (say 1,000 miles in round numbers) with trains of 25 cars moving every 3 min. each way—required the rolling-stock, train-service, and other facilities for train-speeds of 8 and 20 miles per hour.

I take his 8 mile speed because he seems to fancy it for the important reason that "at 8 miles per hour lateral friction nearly ceases." Allow each car 6 hours at termini for unloading, reloading, switching, etc., and run locomotives and men 10 hours on and 10 hours off.

At 8 miles per hour.—We shall want daily, to just do our work:

131,000 Freight-cars,
10,000 Locomotives,
10,000 Enginemen,
10,000 Firemen,
10,000 Conductors,
20,000 Brakemen,
10,000 Cabooses, if each conductor has his own, or
1,000 if they run through.

For the immense traffic he puts on our line, please note the effect of adding 2 miles to his speed-rate. At 10 miles per hour we would want, to just keep our trains moving, 106,000 freight-cars; 8,000 locomotives; 8,000 enginemen; 8,000 firemen; 8,000 conductors; 16,000 brakemen, etc. It is quite unfortunate that "lateral friction" (whatever it may be) did not nearly cease at 10 miles an hour. Return to our 8 mile rate. Each car will thus make 1,000 miles every 131 hours, or 66,916 miles annually, with 8,365 hours in motion on the road, and 401 hours in yard at terminus annually. But this is terrible—only 12½ days out of 365¼, and at least one-half of that used up in switching. If I allow them more hours at termini, for each additional hour I must add 1,000 cars to my above total, and have 500 more cars standing idle at each point, requiring additional track and yard room—all very expensive accommodations. The dilemma is very unsatisfactory, but then Mr. Quincy's proposition is terrible, and for lack of any reasonable escape let us adhere to our 6 hours. There will be constantly on the road 2,500 trains each way—a total of 5,000 trains and engines—so that 5,000 engines will be constantly at home or in house, besides the percentage on 10,000 any one may choose to add for contingencies. Round-house accommodations need not necessarily be provided for the 5,000 engines constantly on the road.

At 20 miles per hour.—If mileage interval has any particular charms to any one, please note that in this case it is just 1 mile, while at eight miles per hour it is only $\frac{4}{10}$ of a mile. We shall require, to just do our constant work:

56,000 Freight Cars,
4,000 Locomotives,
4,000 Enginemen,
4,000 Firemen,
4,000 Conductors,
8,000 Brakemen,
4,000 Cabooses, if each conductor has his own, or
400 if they run through.

Each car will thus make 1,000 miles every 56 hours, or 156,536 miles annually, with 7,827 hours in motion on the road and 939 hours in yard. There will be 1,000 trains each way, total 2,000, constantly on the road; the other 6,000 cars and 2,000 engines will be constantly in yard or house. Strewn along the line we will have car-shop accommodations, facilities, labor, materials, and repairers for 75,000 less cars, because we don't need them, couldn't use them if we had them, and of course won't buy them; machine-shop facilities, etc., for 6,000 less engines which we have turned over to a neighbor who delights to keep that extra number on hand merely to run them at 8 miles an hour; round-house accommodations for 3,000 less engines at least, because the necessary $5,400,000 was not attainable and, required too much interest anyhow; coal-sheds for 3,000,000 less tons of coal, with the buckets, cranes, etc., requisite for its handling; and innumerable less things, materials and fixtures, since we have turned over the leaf of the future and see differently. Instead of an army of train-men, shop-men, car-repairers, foremen, sub-

managers, etc., greater than the army that marched with Sherman to the sea, our head-manager will content himself with the command of a reasonable corps d'armée that will enable him to exhibit a healthy credit for less supervision, and less errors and losses from so many "personal equations."

Speed does affect the amount of rolling-stock and matters roughly indicated so enormously, that you, I and Harry of the future will prefer to run our immense trunk lines to their maximum capacities for tonnage, not at 5, 6, 8 or 10 miles per hour, but at speeds that will keep capital, interest and expenses within reasonable finances; and to this end will in the meantime, gradually perhaps, but surely, mould our road-beds, tracks and equipments into such shape, that when this future traffic and ultimate capacity question are upon us, we may practise economically and safely speeds of at least 20 miles an hour—while Tom, Dick and Josiah Quincy are mortgaging a continent to raise funds enough to provide facilities and pay expenses for performing the same service on their lines at 6, 8, and 10 miles an hour. The number of these imaginary future freight lines is as hypothetical as the possible existence of one, and if one may be reasonably expected, then may hundreds. Let us have done of twaddling about running trains every 3, $3\frac{3}{4}$, 6, 12, 15, etc., minutes, over all these future lines at 5, 6, 8 and 10 miles an hour.

Admitting for the moment—which I do not in fact—that there will be no saving at all in expenses, even then the untold millions saved in rolling-stock and buildings would to most people appear at least significant. Go further and throw these untold millions also into the scale, and even then why must we lavishly use two when one will accomplish the same end in less time? There is much more enjoyment and satisfaction in riding one horse than in riding two, and besides even experts can ride one horse much better than they can two. Space will be needed in the future for sundry things besides railroad cars, engines and buildings; and time may be found as much an object then as now both for the manager and shipper, else, as an illustration, eggs gathered from our prairies and shipped from Chicago might reach Boston as respectable spring chickens—at least for that market. Some goods and trains—as for instance live-stock and all perishable property—we all admit must be transported within reasonable limits of time; but the quickest strain-speed will govern that of all trains since on a crowded thoroughfare all must move at an uniform rate or not move at all. Railroad officials of the future I guess—being something of a Yankee—will have as decided opinions of the daily values of a car and engine as the same class of men have to-day—opinions based on pretty sound premises—and may possibly build better, travel faster, and at less cost than all these monomaniacs on future economical slow speeds seem to admit or imagine. At any rate we will let them do their own work in their own way, feeling that if experience and knowledge count for anything, they will do it much better than we are doing our work to-day.

CHEAP TRANSPORT.

Written for "Van Nostrand's Magazine."

Perhaps the most pressing problem now before the profession, in this country at least, is a system of cheap railroads. We say the most pressing, because the development of our immense resources has become almost entirely a question of transportation, and this development is awaiting solely the solution of the problem proposed. If only our coal and iron regions, our wheat fields—in a word, all the districts where products of small value for their bulk are found, can be reached by railroads of such cheap construction, that low rates of freight will pay 7 per cent. on the capital invested in them, America will rapidly become the leading nation of the world. Certainly, Providence must see that we are not yet fit to occupy this position, or it would have permitted the solution of the problem of cheap railroads to have been reached long ere this.

In the early days of railroad engineering, and mainly under the spell of Brunel's magnificent genius, every effort was made to reduce the road-bed as nearly as possible to the condition of a perfectly level, straight line. The Great Western is probably the best example of a perfect railway

according to early notions. Speed was then supposed to be the great desideratum, and to obtain facilities for that, engineers were lavish in their expenditures, it being supposed that the travelling public and freighters would pay almost anything for rapidity of motion. Now that speed is, with few exceptions, almost entirely eliminated from the question, and cheapness and regularity promoted to the chief places, it is evident that we must look at the requirements of railroad building with other eyes than those of a Brunel.

To-day, the main effort is directed to reducing the first cost of the road-bed and track. The narrow-gauge men claim, and we think with demonstrable correctness, that the whole business of any road can be carried over a 3 ft. gauge. If this be a fact, no track should ever be laid of a greater width, from this time forth, unless under very exceptional circumstances. A determined stand should be taken in this regard, while our railroad system is still in its infancy; for 50 years from now, when Appleton's Railway Guide shall be a thick octavo, the change of gauge would be most difficult to effect. The narrow gauge, *i. e.*, a gauge no wider than necessary, is certainly a most important step towards cheap railroads, for it cannot be doubted that unnecessary width of road-bed entails unnecessary expense.

Mr. Fairlie's brilliant development of the American truck system, is another immense contribution to the cause of cheap railroads. By increasing the powers of the locomotive, he enables it to surmount obstacles which with the old-fashioned engine must be removed. A 100 ft. grade is reduced, as an obstacle, to the condition of (say) a 70 ft. grade, while an abrupt change of direction may be effected in a single chord, as easily as in ten with the long wheel base of the present engine.

We wish we could speak as favorably of the system of cheap transport, described in the March number of this Magazine. After some general remarks, showing considerable appreciation of the importance of cheap lines, the author proposes to operate side lines of light tonnage, by means of strap rails of ordinary gauge supporting the cars and guiding the engine. The driving wheel of the engine to be central, and provided with an india-rubber tire running on a narrow strip of roadway, placed between the strap rails and on a level with their tops. "This strip to be manufactured of any material cheapest to the country in which the same may lie, be it stone or wood, asphaltum or macadam." The author shows that the bite of the rubber tire would be quite sufficient to draw light trains up very heavy grades, and claims that the system would prove cheap and efficacious for the work proposed.

Granting all that the author claims, there is one circumstance which renders the whole system impracticable. Its success depends upon the true bearings being kept in an invariable relative position. Should the central strip from any cause become elevated, the engine would almost inevitably run off the track, while if it became depressed out of reach of the driving wheel, the train would be liable to come to a stand-still. No system of these bearings can ever be practicable, from the impossibility of retaining them in their positions with the absolute precision indispensable to the working of the system.

ON MANUFACTURE OF GUNPOWDER FOR GREAT GUNS, AND ON INCREASING EFFICIENCY OF SMALL ARMS BY IMPROVED AMMUNITION AND SIGHTS.*

By General M. C. Meigs.

All nations have, it is believed, now adopted ideas in regard to gunpowder originating with the late General Rodman, U. S. Army.

All use powder of very large grain, styled by such names as pebble, mammoth, prismatic, cake, etc.

The object is to so regulate the combustion that the charge shall be entirely consumed by the time the projectile leaves the gun, and that it shall not be consumed before it has moved to that point of the bore at which the result is most favorable in creating the greatest initial velocity.

The well-known Perkins steam-gun, with a pressure which could at no time exceed

* Paper read before the National Academy of Sciences.

150 to 200 lbs. to the sq. in., gave to its small projectiles a very considerable initial velocity, sufficient to flatten a leaden bullet against an iron target, and to disperse a considerable portion of each bullet either in small fragments or actually in a melted state.

No charge of gunpowder is used in practice which does not generate a very much more intense pressure in the piece than 200 lbs. to the sq. in. The pressures are among the thousands.

Much of the powder in the state of pebble, mammoth, cake, prismatic, leaves the gun unconsumed; the particles can be seen sailing through the air and giving off smoke like small rockets or shells.

It occurs to me that a new, and I believe hitherto untried line of experiment offers sufficient promise of advantage to be worthy of trial.

At present the material of which all powder is composed is one of almost instantaneous complete combustion—that is to say, the moment any small portion of the composition comes in contact with the heat of ignition it all bursts into flame. Large grains of great density take fire and burn from the surface, but with varying quickness, and the present mode of regulating this speed of combustion is by regulating the size of the individual grains of the composition, and making the grains as dense as possible.

I propose that the composition itself shall be one whose speed of combustion shall be capable of regulation, and to regulate it by graduating the size of the particles of the ingredients of which it is composed.

Using the nitre in small crystals or in particles of certain sizes, determined experimentally, the sulphur and the charcoal in the same condition.

It is manifest that if nitre, sulphur, and charcoal in pieces of the size of a hen's egg are placed in a grate, they will burn more slowly than the same if of the size of pigeons' eggs, of peas, of mustard seed, shot, etc.

It is probable that for each calibre of gun there is a certain size of grain at which the best result will be obtained. It may be that the nitre should be in larger or smaller particles than the sulphur or the charcoal.

All these grains of uniform size for each ingredient should be intimately mixed, so that each particle of sulphur should be associated with its corresponding particles of charcoal and of nitre, and a sufficient portion of ordinary gunpowder should be equally disseminated through the mass to communicate the ignition instantly to every group of these ultimate particles. The groups should be assembled into particles of size also to be determined by experiment.

By this means I think that the speed of ignition could, by a sufficient series of experiments, be so regulated that any charge should be all consumed in the 1000th, 500th, or the tenth of a second, or in any other space of time believed to be most advantageous in its results as affecting the interior pressures and the initial velocities.

REPORTS OF ENGINEERS' SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—A regular meeting of this Society was held at the rooms in New York, February 19th, 1873.

The Secretary presented the following discussion of a paper "upon the Character and Position of Neutral Axes as seen by Polarized Light"—by Louis Nickerson, C. E., of St. Louis, Mo.—read before the Society December 18th, last.

Col. Merrill—This paper opens a field for examination, which promises the most useful results in a matter of vital interest to Engineers: The Laws of Strains in Materials used in Construction. The plan of using glass to find out these laws, brings to mind the practice of physicans in ancient times, of determining the laws of the human body by experiments upon those of the lower animals.

In examining the action of strains within opaque bodies, the method by analogy seems to be the sole one, aided, of course, by what is visible on the surface and detected after fracture.

Further experiments will probably enable us to decide with fair accuracy what is the magnitude of an unknown strain on a glass column, by comparison with the observed effects of a known strain upon a similar column.

The proposed strengthening of tubes by external rings at regular intervals is a curious result of the experiments, and—if confirmed by practice—a valuable discovery. The whole discussion illustrates the interdependence of all branches of physical science; and that no discovery is to be considered useless, no matter how far it is apparently removed from a practical application.

Mr. McAlpine—The civil engineer has rarely to deal with glass as a material of strength,—still, evidently it will be affected in the same way as any similar material—as cast iron. It is a characteristic of this age, that every discovery in science is made useful to the Engineer or Constructor.

Some years ago Prof. Airey devised a system of measuring the strains in each member of a truss, with a model in steel, of which he had exact duplicates. When the model was loaded, a member was struck, and the strain upon it measured by the load borne by the duplicate, when in accord. There we have *sound*, and here we have *light*, to aid in solving an important problem.

Gen. Ellis—Wertheim of Paris invented an instrument for the determination of strains and pressures by the colors of polarized light. Mr. Nickerson's examinations are in the right direction, and it is hoped he will pursue the matter further.

What we want to know is—the elastic resistance to tension and compression in any one substance, and the effect of a weight upon a beam of the same substance; then, knowing by experiment, the elastic resistance in both directions of other substances, we might reason upon the position of the neutral axes of beams made therefrom.

Writers upon the strength of beams err in assuming that equal strains extend and compress the same substance equally (thereby locating the neutral axis of horizontal strains in the middle of a rectangular beam), also that the elastic and ultimate resistances are proportional.

How can polarized light show a neutral axis in a glass beam, supported at the ends, and weighted in the middle; instead of a neutral point under the weight? Everywhere in the beam, except at the central point, there are diagonal strains, which will, as well as the horizontal strains, transmit the polarized rays.

The additional element of strength referred to in the paper is, I think, due to the elastic yielding of fibres which in consequence slip upon each other, without a diminution of their ultimate strength. Otherwise, in a beam under strain, the outer fibres would be ruptured before the others were loaded.

A communication from Gen. Smith—Chairman of the Committee appointed at the Annual Convention, held in Chicago, June 5th and 6th last, to urge upon the United States Government, the importance of a thorough and complete series of tests of American Iron and Steel, and the great value of formulæ to be deduced from such experiments—was read, stating that information is required of what has been done in this direction by other governments, as well as by corporations and individuals here and abroad, of new forms employed, and of new processes of iron and steel making, and their products.

A paper by Gen. W. Sooy Smith, of Maywood, Ill., on "Pneumatic Foundations," was read.

The first two bridges on pneumatic pile foundations, erected in the United States, were one over the Santee River, on the North Eastern Railroad, built in 1855. And the other over the Great Pedee River, on the Wilmington, Columbia and Augusta Railroad, built in 1857.

The air-lock used in sinking these piles, was invented by Alexander Holstrom; it was a cast iron cylinder 6 ft. in diameter, and 4 ft. high—closed at top and bottom by cast iron plates, through which were mem-holes opening downward for entrance and bull's eyes of glass for light; two goose-neck pipes passed through the sides and bottom—one for introduction of air and the other for the discharge of water when it would not escape through the material underneath the pile. A windlass was attached for raising the earth within the pile, all of which was removed by hand.

There were four air pumps, set in a single frame, of such excellent construction that they served, for the sinking of their foundations, those of the Third avenue Bridge, New York, across Harlem River, and of the Leavenworth Bridge across the Missouri River, and are now being repaired for use in sinking the piles for the Little Rock Bridge across the Arkansas River.

Construction of the pneumatic pile piers for a bridge over the Savannah River on the Charleston and Savannah R. R. was begun in the fall of 1859.

The air-lock used was 6 ft. instead of 4 ft. high, and, to save weight, the cylinders of wrought, instead of cast iron. Two defects were soon apparent—one, practically no natural light was admitted through the bull's eyes in the air-lock plates—those in the bottom being covered with dirt most of the time; another, the air-lock was too small to stow the material raised, so that when discharging the same, work in the pile was much delayed.

To overcome these defects, an air-lock was made of less diameter than the pile, so that an annular space was left between the two, in the plate covering the top of the latter—into which bull's eyes were introduced. Through the side of the air-lock was a pipe or trap, inclined at an angle, to discharge readily any material put into it, and arranged for closing at either end; the outer end being closed, the trap was filled with material; the inner end was then closed, the compressed air, thus cut off from the air-lock, liberated, and the outer end opened, when the material would pass out. By reversing the process the trap was made ready to receive material again.

By this modification, no artificial light was required during the day, and at night it could be reflected into the pile, without the inconvenience of candles or lamps burning in a compressed atmosphere.

No detention occurred from this or from voiding the material raised, and nearly thrice as much work was done in the same time as with the Holston air-lock.

It was soon found that the sandy material through which these piles were sunk, could be raised by the escaping compressed air, through a discharge pipe, and delivered outside in a continuous stream;—for this, the mouth of a flexible tube, fitted to the lower end of a fixed pipe, was thrust into the wet sand, and moved from place to place as the material disappeared; the ratio of work done to that with the old air lock, which before was as 28 to 10, now became as 28 to 1.

The improvements thus introduced have been generally used since by Gen. Smith in sinking foundations by the pneumatic process. For the flexible tube, one iron pipe sliding into another with a hempen gasket between, has been substituted, with still better results; thereby 7 men have excavated 6 cubic yards per hour, for several hours: by hand $\frac{3}{4}$ of a cubic yard per day per man is about the rate.

The late war interrupted this work, and also prevented consideration of a plan submitted to the U. S. Light House Board in 1860 for the erection of a light-house on Frying Pan Shoals, or a similar position on the coast, embracing the sinking of a caisson from 30 to 50 ft. in diameter, to any required depth, less than 100 ft.; inside of which a masonry foundation of dovetailed stones was to be laid.

Soon after the war the plan was adopted to the repairing of Waugoshance Lighthouse, located at the western entrance of the Straits of Mackinac, upon a rocky reef $2\frac{1}{2}$ miles from shore. It is a brick tower 24 ft. in diameter, 84 ft. high from water surface to focal plane, and stands upon a

foundation 24 ft. square, consisting of a crib, filled with concrete and rubble masonry—this crib was surrounded by others filled with loose stones, all framed together into one pier 100 ft. square. At this time the timbers put in place in 1848 were decaying under the action of seas, as heavy as any upon the Northern lakes, and the ice, the utter destruction of the pier was threatened.

It was proposed to protect the tower from waves and ice by surrounding it with a strong sea wall 66 ft. long and 48 ft. wide on the outside—8 ft. thick, and semicircular at the ends. An annular pneumatic coffer-dam of boiler iron was built up in place around the tower, large enough to enclose the wall. It was provided with two air-locks, each having a rectangular trap, through which material and workmen passed; and a windlass driven by steam. The dam was suspended by chains from beams resting upon the woodwork of the old pier, and with stones loaded somewhat in excess of its buoyancy. For 6 ft. below the water surface the crib timbers of pine, 12 by 12 in., built up solid and strongly drift-bolted, with round 1 inch iron bolts, had to be cut through. The reef then reached was made up of boulders varying in size from a hen's egg to 10 tons weight; the large ones when found under the edge of the caisson, were first split with plugs and feathers, or undermined, drawn into the caisson, and then split. In some instances where large stones rolled against the dam and kept it from sinking, the dam was allowed to rise, and the stones were rolled inward.

The dam was sunk to a depth of 12½ ft. below the water surface and 6 ft. below the foundation of the tower—which, though not upon bed rock, as expected when the work was begun, was where the boulders (which had lessened in size, as the depth increased) were most perfectly compacted together, and below the scouring action of the waves, from which the dam was protected by the remaining portion of the cribs. The bottom of the dam was then sealed with two successive layers of the quickest setting Louisville cement, each 6 in. in depth, and set under water, which, when the air pressure was reduced, entered through holes left for it in the layers. It was found the 12 in. of cement, thus laid, would not after 4 days' setting resist the pressure of water outside; hence the first three courses of masonry, each 2 ft. thick, were laid in a compressed atmosphere. The stones were dowelled together with iron pins 2½ in. in diameter. The end of each pin was drilled 1 in. in diameter, 3 in. deep, and sawn, so that when in place and a taper bolt was driven therein, the dowell was permanently enlarged.

When the wall was finished, the space between it and the tower was filled with concrete, and covered with flagging. The coffer-dam, which might have been removed for use elsewhere, was left in place.

Work could only be done in the 6 months beginning with May, and frequently it was interrupted by storms. During the first season the chamber to receive the dam was excavated, the machinery was put in place, the dam built and sunk 4 ft. During the second season the sinking was concluded, and seven courses of masonry laid. And during the third season, the work was entirely finished. An average force of forty men was employed. The entire cost, including a new dwelling for the Light House Keeper was less than $200,000. This is the first instance of the sinking of a pneumatic coffer-dam or caisson in this country.

After the completion of this work, Gen. Smith, in 1869, proceeded to put down at Omaha, for a bridge across the Missouri River, the first pneumatic piles sunk west of the Alleghany mountains, and to a depth greater than ever before reached, 82 ft. below the water surface. The material was very difficult to penetrate; it consisted of a fine silt, stratified with layers of coarse sand and tough blue clay, the latter not more than 2 ft. deep, and with a stratum of pebbles or gravel 1½ to 2 ft. deep next to the bed rock.

The first pile went down vertically. The second, after sinking 27 ft., took an inclination which could not be corrected in the next 20 ft. by the various means applied, which, although they failed here, in many other cases have succeeded at a depth of from 40 to 50 ft.

Generally the most effective method is, to excavate the material under the pile, and, with heavy wooden wedges, firmly wedge up the lowermost edge; then, by letting the air escape suddenly, bring the atmospheric pressure and the weight of the pile to bear like a blow. In this case the silt came in so rapidly as to carry the wedges before it.

Another cylindrical section was put in place, thus adding 10 ft. to the length of the pile, making it 16 ft., and with the air-lock 22 ft. above the earth surfaces. A strong frame of 12×12 in. timbers was laid down for a fulcrum, blocks and falls were attached to the air-lock, and a severe strain was put upon the pile. The material was again excavated, and instead of the wedges, a strong beam, cut to the segment of a circle, put down. The pressure was let off, and the pile descended, but without any correction of the inclination, although the timbers of the fulcrum were broken.

A pine strut 8×8 in., 11 ft. long, was set at a slight angle—its top against the leaning pile, and its foot against the pile already in place—without avail; and at last the cylinder broke off 27 ft. below the surface where there was a "cold shut" in the metal.

With 15 ft. of sand in the cylinder, 45 lbs. air pressure to the square inch, did not lift the piece broken off, but 27 lbs. were sufficient after the sand was removed.

This is the only opportunity he has had to measure approximately the friction on a cast-iron pile. The friction per square inch of surface in contact, before the sand was removed, was greater than 1.77 lbs. And after, it was less than 1.39 lbs. This friction must vary with the depth of material, and is diminished when the earth is loosened by the passage of air currents through it. The case instanced differs from that of a pile in place under a load. An important subject of inquiry is—what should be taken as the safe resistance of such a pile in sand, to sinking alone, where no bed rock can be reached,—as along the lower Mississippi, and on the Gulf coast, it may be desirable to sustain structures upon piles or caissons, resting wholly in and on sand.

The next two piles were put down without great difficulty, one at the rate of 10 ft. per day. To cause the piles to sink they were loaded by filling the cylinders with stones, except a central passage or well-hole. Frames built within the

cylinders kept the stones in place. After a certain depth was reached, it was necessary to increase the downward pressure on the pile, by allowing a portion of the compressed air to escape; the pile would then sink from 2 to 4 ft. at a time. The top of the bottom cylinder was covered with a cast-iron diaphragm, through which there was a man-hole closed by a valve opening inward, which, when shut, prevented more sand from entering the pile, while sinking, than would fill the lower cylinder; thereby the tendency to "lurch," and the disturbance of outside material was lessened.

At this stage of the work Gen. Smith was succeeded by Mr. Theo. E. Sickles, who successfully employed levers in forcing the piles down, and corrected the inclination by drilling holes through the higher side at different heights, through which the compressed air escaped, loosened the outside material, and thus lessened the friction against the pile.

Gen. Smith then sank the piers for the railroad bridge across the Missouri River at Leavenworth, Kansas, 3 in number (2 in the river, and 1 on the east bank), upon which, and a stone abutment, 3 spans, each 340 ft. long, were erected. This was finished in two years after its commencement; the difficulties encountered were similar to those at Omaha.

The following conclusions are deduced from an experience of 14 years in sinking pneumatic pile foundations.

1st. The greatest difficulties to be overcome are, first, in keeping the pile vertical; for this it should be made to follow the excavation without a reduction of air pressure; and, secondly, in "righting" the pile when inclined; for this wedging under the bottom, or propping the top on the lowermost side, and drilling through the uppermost side, are the best means yet tried.

2d. The "air lift," as described, is the cheapest and most efficient method of removing sand or mud from within a pneumatic pile or caisson.

3d. A strong and reliable pier can be always built of pneumatic piles—their number, diameter, and the thickness of metal being determined by the conditions of the case.

4th. In cold climates, these piles may be fractured by frost—to prevent which, a filling below the frost line, from 2 to 5 ft. deep of asphaltic concrete, is recommended.

5th. Where suitable timber and stone are to be obtained, at reasonable prices, a single pneumatic caisson can be sunk with greater certainty, and at less cost, than a pier of three or more pneumatic piles, where it has to be sunk for a considerable depth through a soft material to a hard one. A pier of masonry on such a wooden caisson, cellular, with its walls well drift-bolted, and its interior carefully filled, with concrete or rubble, is the cheapest and best bridge foundation yet devised.

6th. Concrete does not "set" well under air pressure; the water was let in through a pipe inserted therefore in the cement, to cover the successive layers as put down; usually, cement 5 ft. in depth would seal the pile, the remainder was added in the open air.

Discussion.—Mr. Martin—The first work he had to do in sinking the pneumatic pile piers for a bridge across the Savannah River, on the Charleston and Savannah Railroad, in 1861, was to straighten up a cylinder which was about 30 ft. in the sand, and considerably inclined.

The method described by Gen. Smith, of excavating underneath the lowermost edge of the pile, wedging it up firmly, and then when severely strained in the right direction by strong tackle, causing the pile to go down by suddenly letting the pressure off—did not succeed, although the pile descended 2 ft. or more. He then excavated under the upper edge, as much as possible, so that the escaping air passed through and loosened up the material on that side; wedged up and strained the pipe as before, and with a battering-ram, made of a 12 in. square oak timber, 12 ft. long, and in the middle suspended from shear-poles, struck successive blows against the top of the pile while it was descending; it was thus quickly brought in to position.

A pneumatic pile is easier kept vertical than straightened afterward; in most cases it may be guided in its descent by a platform attached to wooden piles driven around it.

Gen. Smith presented a plan for sinking to any depth pneumatic piles and caissons, through sand, whereby the excavation is made without exposing workmen generally to the injurious effects of compressed air, which increase with the depth, and, below 60 ft., are dangerous.

For a pneumatic pile, there should be a short section at the bottom, covered with a plate, through which there are a man-hole and valve, a supply, and one or more discharge pipes, the latter made telescopic, and with joints, so that a workman standing on the plate may cause the mouth of the pipe to traverse the surface to be excavated beneath the pile.

Thus air forced into the closed section through the supply pipe, would escape through the discharge pipe, and carry with it the material to be removed.

In a caisson, the same principle may be carried out. Men need enter the compressed air-chamber only to remove an unusual obstruction.

Such a method is required in sinking foundations to very great depths; the greater the depth, the more efficient is the *air-lift* described.

Of course this plan cannot be adopted where the material to be removed will not yield and flow with an air current.

A paper by Robert Cartwright, C. E., of Cleveland, Ohio, on "The Manufacture of Pneumatic Piles," was read.

The bridging of the Missouri River was a necessity to the railroads connecting the East and West of this country. The river is a rapid-running, turbid stream, with a bed of treacherous, shifting material, and a channel which changes at every flood.

The bridge at Omaha has 11 spans, 250 ft. long, and at Leavenworth 3 spans 340 ft. long; both posts truss upon pneumatic pile piers. The manufacture of cylinders for these is here described.

First there was built a brick pit 47 ft. internal diameter, and 14 ft. deep, water-tight, with a foundation in the centre for a 25-ton crane, and four buttresses therefrom, dividing the pit into quarters, each to take two moulds.

For access to the moulds, and to supply air during casting, and subsequent cooling, there was a tunnel from each quarter to a shaft sunk outside of the pit. Each mould was built of fire-brick,

laid in loam, upon a level cast-iron bed-plate, and covered with another similar plate—the two being firmly bolted together. Outside the mould was a casing of sheet-iron,—a space of a foot between the two being filled with spalls, cinder, and moulding-sand, which allowed the passage of escaping gases. The remaining spaces in the pit were also filled with sand. From the centres of each bed-plate up to the top of the mould was a vertical wrought-iron shaft upon which the core barrel centred.

The inside of the mould was coated about ½-in. thick, with loam, brought to a true surface with a "strike" board revolving about the shaft. That the castings might be of uniform section under the difference of ferro-static head, the diameter of the mould at the bottom was made $\frac{3}{16}$ in. less than at the top. The core-barrel consisted of six or more staves, or circular segments, strengthened by ribs cast on them, and bolted to 2 circular spiders, which were attached to a central hollow shaft, bored to receive the shaft fixed in the bed-plate of the mould: the whole being so arranged that the hollow shaft and spiders could be withdrawn together, and the staves left in position, to be afterwards removed singly. The barrel was coated with loam, to which a small quantity of chapped hay had been added—no rope being used.

When the mould was coated and dried, and the core in place, it was covered with a plate or trough, coated with loam, and well fastened down; through this were 12 holes, 1¼ in. in diameter for pouring "sprues," and 6 elliptical holes about 3½ by 1½ in. for "risers;" the last were about 12 in. high and 6 in. diameter at top, and were an effectual substitute for a "sinking head." A casing was then placed about the covering plate, forming a "runner" around the whole top of the mould, connected with a pouring basin, which had two outlets, each stopped by a "straining" gate to retain the slag.

The mould was filled to the top of the risers, the iron entering simultaneously at 12 equidistant points—and, as shrinkage took place, fresh metal was supplied, and churned with coated rods. When the iron was "set," the runner casing was taken away, the "sprues" and "risers" broken off with a sledge, and, in rapid succession, the covering plate and the several parts of the core barrel removed, leaving the red-hot section just cast, in the mould, and free to shrink uniformly as it rapidly cooled, without danger to its shape or soundness. In about 14 hours after pouring, the section (weighing 9 tons) was taken from the mould, which was then freshly coated with loam: the bricks were usually hot enough to nearly dry it. As its parts were withdrawn the core barrel was put together, and then coated with loam, which was almost dried by the heat retained.

The barrel was then placed vertically on a car, and run into the core oven, which was large enough to receive four.

The loam was prepared in a loam mill, consisting of a revolving pan, and two heavy cast-iron chasers; it was with the addition of a little fresh material repeatedly used.

With 8 moulds and 6 core barrels, 1 and sometimes 2 sections were made daily for months. 281 sections were cast, 8½ ft. in diameter, 10 ft. long, some 1¾ in., and the others 1¼ in. thick—each with a 4½ in. inside flange, 2½ in. thick, at each end. Of these, only one was lost, and this by the breaking of a brace after the mould was nearly full. The two flanges were faced in a lathe at the same time, and then each drilled with 61 holes for 1⅛-in. bolts.

A paper by C. D. Ward, C. E., of Jersey City, N. J., giving "Description of Screw Piles for Supporting a 24 in. Water Main across the Providence River, Providence R. I.," was read.

The piles were placed in a single row—12 feet apart—with a cap or rest, on the top of each, in which the water pipe rests.

They were each 22 ft. long, 10 in. exterior diameter, 1 in. thick, and weighed about 2,500 lbs. The largest diameter of screw was 3 ft., and the pitch was 10 in.; there were 2 threads, each making about three-fourths of a turn.

The piles descended from 6 to 8½ in. per revolution, and were put down by 8 to 21 men, with ropes attached to levers 10½ ft., long. The direction of draft reduced the effective leverage to about 7½ ft.

12 piles were put down from 9 to 12 ft each, in sand and gravel, in five days. When regularly moving, the ordinary rate of sinking was about 2 ft. per minute.

AMERICAN INSTITUTE OF MINING ENGINEERS.—The February meeting of this Institute produced the usual number of good things. Abstracts of some of the papers will be presented in our pages.

INSTITUTION OF CIVIL ENGINEERS, March 25th, 1873. Mr. T. Hawksley, President, in the Chair. The paper read was "The Mont Cenis Tunnel," by Mr. Thomas Sopwith, Jr., M. Inst. C.E. This communication might be considered as supplementary to a former paper read in 1864—(Min. Proc. Inst. C.E., vol. xxiii., p. 258—and described (1) the tunnel as completed, with statistics obtained either by actual observation or from the engineers in charge, or from official publications of the Italian Government. (2) The principal changes which had been introduced in the works and machinery underground and at the surface since the summer of 1863.

With regard to the tunnel as completed. The advancing gallery from the Bardonnèche, Italian or Southern end, was connected with that from the Modane or French end of the tunnel by a bore hole, three metres, eighty centimetres long, at 4.25 P.M., December 25th, 1870. The diaphragm of rock was shot away by 5.20 P.M. the following day (Italian time), and Mr. Copello, the engineer in charge of Modane, passed from end to end of the tunnel, entering at the French and coming out at the Italian end. There was an error of about 1 ft. in level at the meeting of the two galleries, but no appreciable error in direction.

The actual length of tunnel was 12,233 metres 55 centimetres (7.6017 miles), or about 15 yards more than was previously stated by the author. The following data, which were now accepted as correct, also varied from those he stated previously:—Modane or north entrance is 3,801 ft. above level of sea; Bardonnèche or south entrance, 4,236 ft.; summit of tunnel, 4,246 ft.; summit of section over tunnel, 9,527 ft.

There were curved tunnel entrances at each end, which, added to the length of the real tunnel, made

the length traversed by the trains 12,846.82 metres, or 7.9806 miles.

In the total length of the tunnel proper (12,233.55 metres), counting from the Modane or northern end southward, the following different rocks were traversed:—Carbonaceous schist, 2,096.50 metres; quartz, 388.50; limestone and dolomite limestone, 355.60; calcareous schist, 9,392.95; total 12,233.55 metres.

It was expected that the difference of level (435 ft.) between the French and the Italian extremities of the tunnel would have insured under all circumstances a steady current of fresh air from north to south; but this had not been the case. The ventilation, although not bad enough to incommode passengers, or to impede the present traffic, was such as to render the work of watchmen, raillayers, and others employed in the tunnel, insupportable at times, and with increased traffic serious difficulty might be experienced. A remedy was being applied by laying a pipe 8 in. diameter from end to end of the tunnel, midway between the two lines of rails, which would be supplied with compressed air from the Italian end, and which would have cocks at short intervals opened as occasion required, by the men at work in the tunnel. Shelter places, or niches one and a half metre broad by one metre deep, were provided at Bardonnèche end, at a distance of 50 metres, alternately on the two sides, and at Modane end in like manner at distances of 25 metres. At each 1,000 metres there was a lamp-room three metres square. The tunnel was walled, with the exception of about 300 yards on the French side; the side walls were 8½ ft. high, and of stone throughout; the arch on the Italian side was principally constructed of brick and on the French side of stone; a brick key was used throughout. There are good side paths of flagged stone 20 in. broad.

The temperature of the air in the tunnel during the progress of the works varied considerably according to the number of men employed, quantity of gunpowder consumed, and quantity of compressed air supplied. Extracts from observations of temperature kept at Bardonnèche, at different distances from the entrance, were given, and it was stated that, since the completion of the tunnel, the temperature of the air had varied from 80 deg. to 90 deg. Fahr.

The author showed by tables the rate of progress made in each year in the galleries from each end, by hand labor and by machine. The greatest progress made in any one month was in May, 1865, when 329½ ft. were driven, and the least progress, after the successful application of the boring machines, was in April, 1866, when 35 ft. (in quartz) only were driven; both of these statements had reference to the Modane end. Better progress has been made at the Italian than at the French end of the tunnel, partly owing to the rocks being more favorable, and partly to the advanced gallery being one of smaller size.

The cost was not yet known officially; it was supposed, however, to have been about $3,000,000.

The following changes had been introduced in the conduct of the works since 1864. In June, 1863, when 1,092.25 metres had been driven from the north, and 1,450 metres from the south end, there was no means actually adopted for ventilation, further than the admission of compressed air by means of cocks from the supply pipe and from that afforded by the large quantity of air exhausted from the perforators in the forehead of the advanced gallery. In 1864 a brattice was placed from each entrance, dividing the tunnel horizontally as far as the walling of the tunnel was completed, the air from the entrance passing along the under side and returning along the upper side. At Bardonnèche the draught was stimulated by the return air being taken up in a conduit to a chimney, the top of which was not less than 300 ft. above the level of the tunnel; this being found insufficient, a fan about 32 ft. in diameter was successfully used to stimulate the draught. At the north end it was found necessary to apply powerful exhausting pumps to extract the vitiated air. By their means fair ventilation was obtained during the prosecution of the works.

Hand labor was found insufficient for the enlargement of the advanced gallery. It was found also insufficient to carry away the rock extracted. In 1868, therefore, the machine perforators were applied for this purpose, at an increased cost as compared with manual labor, but with great success in advancing the rate of progress. Water column compressors were used at first, but the breakages being frequent and the duty performed unsatisfactory, pumps worked by water power were substituted, and gave excellent results up the time the works were completed.

The alterations made since 1864 in the "perforators," were described. They were simpler in construction, better balanced, and require less repairs than formerly.

The author had not obtained information on the duty performed by the compressors; it is probable, however, the production of 12,662 cubic ft. of air compressed to six atmospheres, or five above atmospheric pressure, would require, with good machinery, about 14-horse power.

The different operations of boring, charging, firing and removing the rubbish were, in the last two or three years, performed with great celerity, and three complete shifts or repetitions of each operation were worked in 24 hours. The strong doors formerly employed, fixed from 100 to 150 metres from the forehead of the gallery, and removed from time to time as it advanced, behind which the frame carrying the set of perforators was removed previous to the explosion of the holes bored, were suppressed, and the saving of time thus obtained more than compensated the occasional damage done by loose pieces of rock which came in contact with the machinery. The author was informed by the employés, that supposing twenty perforators were required for the current work, a stock of eighty was sufficient to insure at all times a supply of them in thorough repair.

Notwithstanding the great cost which was said to have attended the construction of this great work, amounting, if the total figure of £3,000,000 were correct, to £206 per lineal yard, there was reason to suppose that, with the experience now acquired, a similar work could be performed at a cost of £100 per yard.

The time occupied in passing through the tunnel by the train was about 25 min.

SOCIETY OF ENGINEERS.—At a meeting of the Society, Mr. W. H. Fox read a paper on "Continuous Railway Brakes." The author, in his opening remarks, referred to the paper he read

before the Society in December upon the same subject, in which he described the chain and the hydraulic brakes. He then considered generally the conditions which a continuous brake should fulfil, and which he had set forth in detail in his previous paper. He also gave the results of his investigations as to the retarding force required to stop a train within a given distance. That force was shown to be variable, owing to the variable conditions of traffic and weather. As a general result, however, he had found that a train travelling at the rate of 60 miles an hour might be stopped within a distance of 220 yards in ordinary weather, by a retarding force equal to 18 per cent. of the train weight. Mr. Fox then proceeded to describe the Westinghouse brake, in which the actuating power is compressed air, explaining its arrangement and details by the aid of a set of carefully-prepared diagrams. He gave the results of experiments he had made with a train fitted with this brake, which demonstrated its efficiency, and showed that it complied very closely with the conditions he laid down as necessary for a continuous brake to fulfil. The author then described Chapin's electric brake, illustrating its construction by diagrams, and explaining how that the power was applied by means of electro-magnets, which, acting upon friction clutches, caused the brakes to be put on through intermediate gear, arranged beneath each carriage. The author referred to the experiments he had made in order to ascertain the amount of retarding force capable of being exerted by the electric brake, which he found to be ample for the purpose. The author stated that the electric brake, although at present in a somewhat experimental stage, nevertheless complied with most of the conditions he had named. It was, however, being further developed, and by the light of his present experience he considered it would ultimately prove a success. The meeting was attended by a number of railway engineers and managers, who took part in the discussion upon the paper, the subject of which is attracting considerable attention at the present time. The usual ballot for members and associates took place at the close of the meeting.

IRON AND STEEL NOTES.

HOT BLAST.—Professor Akerman, of the Polytechnic Institution of Stockholm, and Professor Peter Tunner, of the Mining School of Leoben, in Austria, have lately published their views on the influence of hot blast in the blast furnace. The former contends that the great increase of temperature, and consequent economy of fuel, is chiefly attributable to the circumstance that the heat, which is carried by the blast into the furnace, as compared with that created by the combustion of the fuel, is introduced therein without increasing the volume of gases, as a greater bulk of expanded gases escaping at the furnace top will naturally carry a greater amount of heat with it. Seeing, however, that blast of only 350 to 450 deg. Fahr. will cause an economy of 25 per cent. of fuel against cold blast, Tunner means that besides the actual quantity of heat which the blast carries with it, its favorable influence must be looked for in the fact that it facilitates a rapid and complete combustion of the fuel, forming carbonic acid only, which again is not so easily to be reduced into carbonic oxide as Akerman and Bell seem to take for granted. While Akerman is of opinion that for producing white forge pig the temperature of the blast should not be raised over about 500 deg. Fahr., it may be opposed to this, that in Styria white and mottled pig iron are constantly produced with hot blast of over 900 deg. Fahr., when the burden is only fluxed with somewhat more lime, the pressure of the blast diminished, and the crucible widened to some extent. The Wasseralfingen system of horizontal and elliptical heating pipes utilizes the heat of the stove better than vertical pipes, as the cold air during its passage through the heating stove comes in contact with pipes of ever increasing temperature until it goes to the blast furnace; the absorption of heat being much more perfect when the pipes have a proper width in their greater diameter, so that the blast gets time to take up heat from their inner surface, when the stove is sufficiently high and wide to allow of a perfect mixture and combination of the air and heating gases. It is evident, when the cold blast enters the heating apparatus at its coldest, and leaves it at its hottest part, that its temperature will be always somewhat less than that of the pipes which it passes; that it consequently is in a still fit state for taking up heat from the latter. As cast-iron pipes will limit the degree of temperature which is obtainable, through their own fusibility, the Siemens regenerative principle has been also applied for heating blast. The Cowper apparatus seems to be more liable to become choked than that of Whitwell, which requires cleaning only once every three months. The latter was lately materially improved by enlarging considerably of its first compartment: although its surface of contact was materially lessened the temperature obtained was much greater, owing to the better combustion, and the increased delay of the gases in the widened chamber. Though the regenerative system offers many advantages over the pipe system, it has not found much favor with Continental iron works, because it requires a large area, and is not so easily controlled and repaired as the latter.—*Engineering.*

STEEL WORKS IN RHODE ISLAND.—Among the most interesting of the new enterprises in the iron business of this country, both from a general and a local point of view, is the establishment of a new steel works at East Providence on the Wilson-Bessemer system, the general features of which we describe in another column. The introduction of the Swedish method of making Bessemer steel would in any case attract attention, and the establishment of large works in Rhode Island, with the intention of utilizing the exceedingly dense anthracite coal of that State, is a matter of no small local importance. As will be seen from the description, the process is not the pure Swedish, but a modification intended to add to the simple apparatus of that method the ease of control which the English plant affords. That there is strong faith in the results, the investment of the large sum of money necessary for such works is sufficient proof. Building is now going energetically on.

Another enterprise connected with these works is worthy of mention. A Siemens-Martin plant is also under construction and partly finished. The gas generators are already up, and the masons are

at work upon the regenerators and furnaces, so that it is hoped steel will be turned out by June. The establishment enjoys the services of Mr. Jones, formerly connected with the works of Mr. Siemens, the patentee of the furnace, in Swansea. This gentleman has long been employed in the manufacture of Siemens-Martin steel, having made some of the first steel of this sort ever produced. He has since had experience in the same work both on the Continent and in this country. We believe it is the intention to introduce the production of steel direct from the ore by the process of which Mr. Siemens is the inventor, and which has long been, and which is now successfully carried out on a large scale in his Swansea works. The Providence works, therefore, bid fair to be the first in this part of the world to found a practical and successful method of direct production of steel from the ore, a desideratum which has ardently been sought by so many inventors. These few notes show that the works in Rhode Island are in the hands of intelligent and energetic men, and sufficiently bear out the assertion with which we began them—that the new establishment deserves attention, as we hope it will win success.—*Engineering and Mining Journal.*

THE American Pig Iron Manufacturers' Association met at the St. Nicholas Hotel, New York, on Wednesday, February 19th, A. B. Stone, President, in the chair. There was a fair attendance of members. Mr Dunlap, the Secretary, read a long and interesting statistical report. The production of pig iron in the United States in 1872 is estimated at 2,388,250 tons of 2,000 lbs. each, and the number of new furnaces built and begun in the same year is reported at 100. A friendly communication having been received from the American Iron and Steel Association, regarding the union of all organizations connected with the iron industry, on the motion of Mr. J. C. Kent, the following committee was appointed to confer with the other associations on the subject and report at the June meeting:

A. B. Stone, Cleveland; Edward L. Cooper, New York; Wm. Firmstone, Glendon, Pa.; Henry McCormick, Harrisburg; Gen. James Pierce, Sharpsville, Pa.; A. B. Cornell, Youngstown, Ohio; A. B. Meeker, Joliet, Ill.; Jas. I. Bennett, Pittsburgh; O. W. Potter, Chicago, Ill.; J. H. Maxon, St. Louis, Mo.; Sam'l Thomas, Catasaqua, Pa.; Joseph C. Kent, Phillipsburg, N. J.; W. F. Bartlett, West Stockbridge, Massachusetts; J. H. Hall, St. Louis.

IMPROVEMENTS IN THE MANUFACTURE OF CAST STEEL.—From various recent notices in our columns, it will have been seen that foreign metallurgists have been turning their attention to the tungsten alloys of iron, as the basis of new or improved processes of manufacturing cast steel. M. H. A. Levallois, No. 26 Rue de Chabrol, Paris, in France, metallurgist, has, we notice, recently introduced and patented some such improvements relating to the production of a combined quality of cast steel not easily liable to rust, and the cost price of which is about the same as that of ordinary cast steel of good quality, varying according to the proportion of the elements employed.

The improved process admits of perfect regularity in the manufacture of this particular quality of steel, which is composed of an alloy of iron, tungsten, and nickel, in the following proportions (thereabouts) by weight:

For the first quality:—Soft iron, 93 parts: tungsten, 6¼ parts; and nickel, ¼ part.

For the second quality:—Soft iron, 95 parts; tungsten, 4¼ parts; and nickel, ¼ part.

For the third quality:—Soft iron, 97 parts; tungsten, 2¼ parts; and nickel, ¼ part. In proportion to one hundred parts in each case.

The furnaces and crucible used for this process are the same as those ordinarily employed in the manufacture of steel.

The tungsten and nickel are mixed together and enclosed with a flux in a soft sheet-iron tube, in the proportion of one part of the flux to one hundred parts of metal. The tube is placed in the centre of the charge, which is sprinkled over with a quantity of the flux, varying in inverse proportion to the quantity of metal treated, between one-half of one part and two entire parts of flux to one hundred parts of metal. As soon as the mass has attained a liquid state it is run off in the usual way into a sand or metal mould, the latter being coated with a mixture of clay and per-carburet of iron. Before and during the process of running off the fused metal, a vacuum is produced either in the sand or metal mould by covering the bottom of the funnel with a parchment membrane, which is destroyed by the contact of the fused metal. This membrane is fixed between the funnel and the tedge. When the alloy is run into a metal mould the ingot is removed as soon as it becomes solidified, annealed in a closed vessel, and allowed to cool gradually.

The flux preferably employed is composed as follows:—In 100 parts, 36 of common boric acid or sub-borate of soda, 32 of calcined silex, and 32 parts of washed carbonate of lime. These elements are pulverized in a mortar together and introduced in small quantities into a crucible at a white heat, liquefied, and run off on to a fluted cast-iron plate, and, lastly, the flux thus obtained is crushed into small pieces before it is made use of.

The steel produced by the above process may be hammered in the same way as ordinary steel.

RAILWAY NOTES.

AMERICAN LOCOMOTIVES IN RUSSIA.—The "Russian News" reports the experiments made between St. Petersburg and Laubane, November 25, with a Baldwin locomotive made to burn anthracite coal. With a train of ten cars it passed over the heaviest grades at the rate of 60 versts (10 miles) an hour, and burned in running 130 versts 62 poods (2,232 lbs.) of anthracite. These engines, it is believed, will be of great service in the south of Russia, where there are unworked mines of anthracite and very little wood, but where heretofore wood has been burned. "La Bourse," of St. Petersburg, also reports the trial, and describes the construction as follows: "The frame is solid instead of being of plates; the construction of the cylinders, the manner in which they are adapted to the machine, and the mechanism of all the details which enter into the construction of a locomotive excel anything of the kind ever seen. But the most striking feature is the immense fire-

box, about 9 ft. long, which forms the essential part of the system of heating with anthracite. Grates formed of several ranges of tubes, one above the other, extend from front to rear in the furnaces. These tubes communicating with the water-spaces, the water circulates in them constantly, so that the interior walls are protected against the consequences of the intense heat produced by the combustion of anthracite. * * * The engine worked wonderfully well all the time, and it was noticed that there was no heating of the journals, such as is common in all new locomotives."

THE total production of rails in the United States during last year is now estimated at 775,733 tons, of which amount 715,691 tons were of iron, and 60,042 of steel or steel-headed rails. The production during 1871 in each separate State is stated to have been as follows:—Pennsylvania, 335,604 tons; Illinois, 91,178 tons; New York, 87,022; Ohio, 75,782 tons; Maryland, 33,941 tons; Wisconsin, 28,774 tons; Massachusetts, 28,864 tons; Michigan, 14,000 tons; Maine, 13,383 tons; Indiana, 12,778 tons; Tennessee, 9,667 tons; Missouri, 8,200 tons; New Jersey, 6,700 tons; Kentucky, 6,000 tons.

ENGINEERING STRUCTURES.

THE ST. GOTHARD RAILWAY.—The machinery to be used for piercing the St. Gothard is now in a forward state. The large turbines for driving the air-compressors are being made by Messrs. Escher, Wyss, and Co., the well-known engineers of Zurich, who are also construct ng the heavy portions of the air-compressors, whilst the more delicate parts are in the hands of M. Plainpalais, of Geneva. The erection of the temporary machinery, made in Belgium (which will be used until the permanent machinery is ready), has been somewhat retarded on account of the heavy floods during the last few months. The experiments with some Anglo-American tunnelling machinery at Geneva are said to have given most satisfactory results, and there seems to be no doubt of its being adopted for the tunnelling of the St. Gothard. The question respecting the purchase of the machinery and plant used at the Mont Cenis Tunnel seems at last to have been satisfactorily arranged on both sides, M. Favre, the contractor, being exonerated from the agreement by which he was bound to purchase all the plant from the Italian Government. It appears now that it is thought advisable to retain the air-compressors at Bardonèche and Modane, and M. Favre has agreed only to take a quantity of pipes that were used for the transmission of the compressed air, the reservoirs, earth wagons, and some of the old tunnelling machines. The advancement in the tunnel at the north side, at Göschenn, up to the 31st December, was at the rate of only 0.30 per day, the heading here driven in the hardest granite, the total length driven up to that date being twenty metres. The number of persons employed at this end is about 100. At Airolo the rock met with is somewhat softer, and 102 metres were tunnelled up to the close of the year. At this end the masonry is also begun, and from 170 to 200 persons are employed. Specimens of every description of rock that is met with during the excavation of this tunnel will be kept, so as to form ten collections, sets of which will on their completion be given to the Italian and German Governments, and to some of the technical schools of Switzerland. At the offices at Göschenn and Airolo a complete geographical record of the strata met with during the tunnelling operations will be kept, as also a register of the daily metrological observations that are taken.—*Journal of the Society of Arts.*

THE HOOSAC TUNNEL.—The headings from the Eastern Portal of the Hoosac Tunnel and from the Central Shaft, were joined December 12th 1872, at a distance of 11,274 ft. from the Portal and 1,530 ft. from the Shaft. The latter is 1,030 ft. deep, and had required the pumping of 250 gallons per minute for some months. Of course this junction gives drainage.

Edward S. Philbrick, the Consulting Engineer of the State of Massachusetts, reports as follows of the accuracy with which the headings joined. "Having taken the first possible opportunity after the clearing away of the smoke, I visited the tunnel, and, with Mr. Frost and his assistant engineers, spent a day in connecting the lines, with the view of making such modification as necessity might require. I was the first man to measure the discrepancy after the points had been fixed from the east to the west at the place of meeting, and found it to be just $\frac{5}{16}$ in. of lateral error.

The vertical error amounts to $\frac{1}{10}$ ft. or $1\frac{1}{4}$ in., nearly, ascertained by comparing the *inside* levels with the levels which were run *over* the mountain in 1870 by Mr. Frost. The success of this as an application of the exact sciences depends more upon the persistent industry of the engineering corps than upon any new methods employed. The projection of a definite direction from the bottom of a shaft, where magnetic direction is useless, is no new problem, but I do not remember of another instance where a horizontal line has been so exactly extended for a distance of over 1,500 ft. (over $\frac{1}{4}$ mile) from the bottom of a smoky pit over 1,000 ft. in depth and only 23 ft. in diameter. Nor another instance where a tunnel has been cut with such exactness for $2\frac{1}{4}$ miles from its portal without a communication with the surface. The processes are old in their essential parts, but the detail has been worked out by endless patience on the part of the whole engineering corps. Amid falling rocks and suffocating smoke, surrounded by the most depressing circumstances of danger, darkness, filth and monotony, those men have plodded on for day after day and month after month for the past years, with none of the exhilaration which attends ordinary field work in the open air. It may be a satisfaction to all who have had a hand in it to meet with such success.

I wish it to be known that American engineering is not behind the rest of the world in precision, where such a result can be attained by skill and patient industry, and think the result will be appreciated by all lovers of exactness.

THE highest bridge in the world is said to be the Verrugas Viaduct, on the Lima and Oroya Railroad, in the Andes of Peru. The viaduct crosses a mountain torrent, called the Agua de Verrugas, in a wild and picturesque locality, 12,000 ft. above the level of the sea. The structure consists of four deck spans of the Fink type of truss, three of which are 110 ft. long, and one, the con-

tral span, 125 ft. long. The spans rest on piers built of wrought iron columns. The piers are 50 ft. long by 15 ft. wide on the top. There being three piers, the total length of the viaduct is 575 ft. The piers are the principal feature of interest, and are respectively 145 ft., 252 ft. and 187 ft. high. Each pier consists of twelve legs, which in plan form a rectangle. The legs are composed of a series of wrought iron six-segment columns, in lengths of 25 ft,, connections being made by cast-iron joint boxes having tenons on each end running into the column. The tenons and the face of casting against which the column bears are machine-dressed, so as to obtain an accurate fit and perfect bearing surface. The columns have an exterior diameter of 12 in., and a diameter, including flanges, of 16 in. Compared with other works of a similar type, such as the Crumlin viaduct, which has hitherto borne off the palm, it is far ahead, both in magnitude and perfection of details.

ORDNANCE AND NAVAL.

A STEAM FERRYBOAT FOR THE GRAND TRUNK.—A steam ferryboat, named the International, which has been built for the Grand Trunk Railway Company, of Canada, is designed to carry as many as 31 cars at one time across the St. Clair river, between Port Huron and Sarnia. With the exception of her deck covering and guards, she is built of iron. The hull is 226 ft. in length, by 40 ft. beam and 14 ft. depth. The boat weighs scarcely 600 tons light, much less than a wooden vessel of the same capacity. When loaded she draws 6 ft. 4 in. forward, and 7 ft. 8 in. aft. Light, she draws 6 ft. aft, and 4 ft. 6 in. forward. The speed of the boat is about 9¾ miles per hour. The hull was built by Palmer's Shipbuilding and Iron Company Limited)) of Jarrow, England; it was then taken to pieces, shipped across the Atlantic, and put together again at Port Erie, opposite Buffalo, where the boat was launched and received her machinery. The latter comprises two separate high pressure steam engines of 150 horse power each, which drive twin screws 9 ft. in diameter. The cylinders are 30 in. in diameter, with 30 in. stroke of piston, acting directly on the shafts, which are 8½ in. in diameter. The engines are supplied with steam from separate cylindrical boilers, each 7 ft. in diameter and 19 ft. in length, including furnace, and containing 156 3-in. flues 12 ft. in length. The engines and boilers were built by Gilbert & Co., of Montreal.

NEW GUNBOATS.—By the launch of the composite screw gunboats Zephyr and Ariel from Chatham Dockyard, an addition has been made to a class of handy vessels which will prove exceedingly useful for operations in rivers and shallow harbors where vessels of a larger size would be unable to enter. Each of the gunboats is built on the composite principle, iron being used wherever practicable, with an outside planking of wood. Being intended to carry an exceptionally heavy armament for their size, they are constructed of the greatest possible strength, while the machinery with which they will be supplied will enable them to steam at between nine and ten knots an hour. The length of each vessel is 125 ft.; breadth, 23 ft. 6 in.; depth of hold 12 ft.; and burthen, 295 tons, with a displacement of 408 tons. They will be engined with machinery of 360-horse power (actual), and will have a complement of 60 officers and men. The armament of each will consist of two 64-pounders, on slides, and two 20-pounder Armstrongs.

BOOK NOTICES.

WORKS IN IRON; BRIDGE AND ROOF STRUCTURES. BY EWING MATHESON. London. For sale by D. Van Nostrand.

Although England would be allowed to stand in the first place as a manufacturing nation, it is remarkable how scanty is the information which has been published by any of those firms which have won for the country this rank. The practice in a manufactory becomes a "trade secret," which is guarded with a jealousy not less than that of the ancient Egyptian priests for their knowledge. Take any branch of English manufacturing industry, and what treatises are there upon it which have been written by practical manufacturers? In engineering the only name we can call to mind at the moment is that of Sir William Fairbairn, and in his case the philosopher has almost overpowered the manufacturer. We need not enter into any consideration as to the causes of this; the disadvantages, at least, are apparent, and form part of the reasons why so many men, eminent in particular branches of industry, will be found to be so indifferent to everything in the way of "literature" which might be supposed to belong to their craft. For these reasons we do not think worse of Mr. Matheson's book because the author belongs to an eminent engineering firm, and that nearly every one of the works which are illustrated or described, have been carried out by that firm. On the contrary, we think it is worthy of especial regard, because there is the novelty of having structures in iron considered not merely as to their design, but as to their construction as well as their cost. There is, consequently, no need to compare the work before us with other treatises on the subject. The class of information contained in it will not be found elsewhere, and it may therefore be read with profit by those who are familiar with the many excellent books on the theory of iron construction which have been published in England during late years.

Mr. Matheson's book is divided into two parts, viz., Bridges and Roofs and Buildings. Commencing with a practical description of the varieties of iron employed, there follow chapters on the design of bridges, their construction, foundations, transport, and erections. To this part of the work about 130 pages are given, which are written in a remarkably clear style and without any of that affectation of mathematical refinement in the reasoning which renders many an engineering work no more than a delusion. Examples of thirty bridges follow. These are of all sizes, from simple cattle passes of 12 ft. span up to bridges of 150 ft. span, and all of them have been manufactured by the author's firm, Messrs. Handyside & Co., of Derby. These works are very liberally illustrated.

The second part of the book is devoted to iron roofs, windows, and to buildings in general of that material. Among the works described are the roof of the Agricultural Hall, at Islington; Mr.

Bessemer's conservatory at Denmark Hill, which was designed by Messrs. Banks and Barry; the winter garden at Leeds, by Sir Gilbert Scott, R.A.; the conservatory in the Horticultural Gardens, an Indian kioskque designed by Mr. Owen Jones. This part is of especial interest to architects. Appended to the book is an excellent vocabulary of French, German, Italian and Spanish technical terms. In conclusion, we have no hesitation in stating that Mr. Matheson's work is one of the most practical books we have lately met with.

MANUAL OF METALLURGY.—Illustrated by a hundred Engravings. By GEO. H. MAKINS, M. R. C. S., F. G. S., late one of the Assayers and Referee to the Bank of England. Second Edition. London: Ellis and White. 1873.

We are glad to welcome a new edition of Mr. Makins' excellent manual, in which, by thorough revision and the re-writing of those parts which had become either obsolete or inadequate to the importance recently acquired by some departments of metallurgy, the author has achieved his object of making the work a handy and condensed manual for a variety of practical purposes. The adoption of the new form of chemical nomenclature was, of course, requisite; and one of the best features of the work is the largely increased number of woodcuts, explanatory of processes, and illustrative of the most improved forms of apparatus.

In thus expanding his work to 592 pages, the writer has departed from the original special aim of his manual, with the view of making it as useful as possible as a condensed handbook for the general student. He has thus certainly greatly increased the value of the treatise. The author amply acknowledges his obligations to the voluminous works of Dr. Percy, to Bruno, Kerl, Phillips, and other writers, and throughout his pages he is careful to give constant reference as to what has been discovered or affirmed concerning the many chemical and mechanical processes by the leading chemists and engineers, English, German, and French, whose papers—published in the Transactions of Societies and elsewhere—afford the most recent and trustworthy information. To Mr. Griffith, assayer, Bank of England, he is indebted for some valuable information upon lead refining and desilverizing, and to Mr. J. Napier, Jr., for details of the Mexican plan of amalgamation as carried on at Guanaxanto, etc. The work bears such ample traces of careful and extensive reading and skilful condensation, that we cannot hesitate in recommending it as a capital manual of metallurgy.

A TREATISE ON THE STRENGTH OF BRIDGES AND ROOFS, with Practical Applications and Examples, for the Use of Engineers and Students. By SAMUEL H. SHREVE, A. M., Civ. Eng. New York: D. Van Nostrand. 1873.

A simple and clear treatise on this subject, so arranged as to be available to engineers in the daily exigencies of practice, is a very desirable thing; and those who have read Mr. Shreve's articles on the subject, in Van Nostrand's "Eclectic", will be glad that he has taken the step of publishing this book. The plan of the work is logical and satisfactory. The part we like least is the introductory chapter. Mr. Shreve is not happy in his statement of elementary principles. A student, unacquainted with the mechanical theorems involved, will find it difficult to follow him; and, on the other hand, the student already familiar with the subject will not be satisfied with this incomplete and obscure exhibition of them. The law of the lever, as given on page 2, is rendered inaccurate by the careless use of the word *farther* instead of *other*. But, this introduction being passed, the author goes at the real work before him in a straightforward and thorough way. Beginning with the simple truss, supported at the ends and loaded at the centre only, he discusses successively the modifications of this case presented by the different positions and uniform or irregular distribution of the constant load, and then by variable and moving loads. The simple truss with inclined struts and vertical ties, and trusses with vertical struts and inclined ties, subject to constant and to moving loads, are analyzed and discussed at length, in natural succession, from the simple truss to the double truss with even number of panels, the same with odd number of panels, and so on through the triple and quadruple forms. Another chapter introduces the element of horizontal chords with struts and ties of equal inclinations. This is followed by a chapter on trusses with horizontal chords and inclined braces, the ties having a different inclination from the struts; then come inclined trusses or rafters, triangular trusses, bowstring trusses, lenticular trusses, and several varieties known by the name of their inventors, as Kiulenberg, Bollmann, and Fink. The book concludes with a treatise on the resistance of different materials to compression and tension—these being the only strains to which structures of this kind are subjected—at least when they are properly made. The diagrams in the book are small, but intelligible, and suitable for the demonstrations.

It is a noteworthy point that all the calculations are made algebraically, without the use of the higher mathematics. This renders them more useful to those of us who are so long out of school as to be rusty in our reminiscences of the calculus. Mr. Shreve does not express opinions concerning the merits of this or that construction; he merely gives the means by which every structure may be tried and its merits unerringly determined.—*Engineering Mining Journal.*

THE STORY OF THE EARTH AND MAN.—By J. W. DAWSON, LL.D., F.R.S., F.G.S., etc. London: Hodder & Stoughton. 1873. For sale by D. Van Nostrand.

Every geologist has his own way of teaching his science. One will collect facts, and build up general laws from them; another will begin with the layer of earth under his feet and work downwards, till he gets lost in the immeasurable distance of time; while a third will commence with the first moment of time, and trace the history of the earth to the present age. Principal Dawson adopts this latter plan, and gives in narrative style an account of the changes undergone by the earth between its nebular origin and the advent of man upon its surface. The book is not a mere digest of current geological opinion, but a clear statement of the principal facts of the science, tinged with the individuality of the writer, who is both firm in the assertion of his own views, and candid in the statement of those of others. It forms an excellent outline of geology for the student, who may fill it out with materials from more detailed

manuals, and in its present form, as when originally published in the "Leisure Hour," it will make sound reading for those who dare not read other geological works without trembling for their faith.—*Iron*.

REPORT ON THE HYDRAULIC LIME OF TEIL. Its fabrication and use in the construction of marine works, canals, aqueducts, sewers, tunnels, railroads, bridges, buildings, foundations, floors, artificial stone, etc. By LEONARD F. BECKWITH, C.E. 8vo. pp. 78. Illustrated. New York: D. Van Nostrand.

The author of this report is a graduate of the Ecole Centrale of Paris. He has made the study of cements and artificial stone a specialty, and is probably more familiar with this important branch of engineering and architecture than any writer in the country. The book will be found to possess practical value, on account of the directions it contains for preparing hydraulic cement and artificial stone. There are several interesting plates, showing what structures have been built of the material it is proposed to introduce into this country, together with tables of analysis and estimates of cost. It is a valuable contribution to the literature of the subject.

LESSONS IN ELEMENTARY ASTRONOMY. By RICHARD A. PROCTOR, B. A. London and New York: Cassell & Co. 1873. Sold by D. Van Nostrand.

In the compass of a small shilling volume of 144 pages, Mr. Proctor has collected a vast amount of interesting information, illustrated by 43 wood-cuts. In its perusal, the student will be brought into contact with many of the most interesting facts connected with the solar and stellar systems, and be furnished with a fair knowledge of the means of practical observation. Mr. Proctor has frequently exhibited both skill and judgment in the selection of astronomical topics for popular discussion; and students and young people are to be congratulated in having the services of so experienced a writer. This little book is written with the author's well known lucidity of expression, and it is in every respect a creditable production.—*Iron*.

ELEMENTARY PHYSICAL GEOGRAPHY. By RICHARD A. PROCTOR, B. A. London: Cassell. 1873. For sale by D. Van Nostrand.

In this volume the author has explained, with almost more than his usual clearness, the leading relations of the earth as a planet, and the prominent features and functions of land, sea, and atmosphere upon its surface. About three dozen carefully prepared maps and diagrams greatly enhance the value of the book, on which, though so small, much well-directed labor has evidently been expended. "As I hold," says the author, "that one of the great purposes which the study of science should fulfil is to awaken the mind to efforts toward the explanation of physical facts, I have not wholly refrained—elementary though the work is—from the discussion of the various theories which have been offered in explanation of the more remarkable phenomena of ocean, land, and air." The book is thus unlike the general run of works of the kind, and by so much, superior to them.

THE YEAR BOOK OF FACTS IN SCIENCE AND ART: exhibiting the most important Discoveries and Improvements of the past year in Mechanics and the Useful Arts; Natural Philosophy; Electricity; Zoology and Botany; Geology and Mineralogy: Meteorology and Astronomy. By JOHN TIMBS. London: Lockwood & Co. 1873. For sale by D. Van Nostrand.

This celebrated annual maintains the high character it has so deservedly acquired, and Mr. Timbs and the publishers are alike to be congratulated on their perfectly indispensable record of the scientific annals of 1872. The volume, as is well known, consists of extracts from scientific journals, and, as usual, "The Mechanics Magazine" stands at the head of these, leading off with 37 extracts. There is a beautiful steel-engraving of a photograph of Dr. W. B. Carpenter, worth the price of the volume, with a prefatory memoir of that celebrated physiologist.

MISCELLANEOUS.

THE ARCHITECTURE OF THE WORLD OF ATOMS.—The eminent French physician, M. A. Gaudin, following in the footsteps of Ampere, has been investigating the atomic, molecular, and crystalline constitution of bodies, and has recently published the results and theories to which he has been led under the above title. His standpoint is the existence of chemical atoms, such that the distance apart from their centres is but the 100-millionth part of a millimetre (the 2,500-millionth part of an inch). To give some idea of the prodigious minuteness, so to say, of these atoms, he states that in a drop of water weighing a decigramme (about a grain and a half) there would be as many atoms of oxygen and hydrogen as there would be grains of sand one millimetre (the 25th part of an inch) in diameter covering the bed of the ocean (assumed at half the surface of the earth) to the depth of 600 metres. These atoms are held by M. Gaudin to be spheroidal agglomerations of particles distinct and yet more minute, viz., the very atoms of the universal ether. His theory of combination is, that an atom of one kind is placed between two others of a different kind, exactly on the lines joining their centres. On this simple principle he assumes files of atoms aligned and equilibrated mutually, by 3, 5, and 7 in number, and with these atomic files he arrives at all the molecular arrangements indicated by chemical formulæ, in which are invariably found atomic systems perpendicular to the axis, also placed and equilibrated mutually in similarly parallel manner. Similarly with the phenomena of crystallization, which he refers to parallel and symmetrical disposition of the molecules, forming, likewise, molecular systems perpendicular to the axis. In right prisms, square or regularly hexagonal, and in the rhomboid, the molecules preserve a constant and invariable distance apart in the systems perpendicular to the axis and perfectly equilibrated; while in the right rhomboidal prisms, singly and doubly oblique, the molecules observe two unequal distances; and it is this inequality that produces the phenomena of double refraction in crystals of unsymmetrical systems. M. Gaudin's theories are bold and novel, and worthy of discussion, particularly in their bearing on crystallization and mineralogy.